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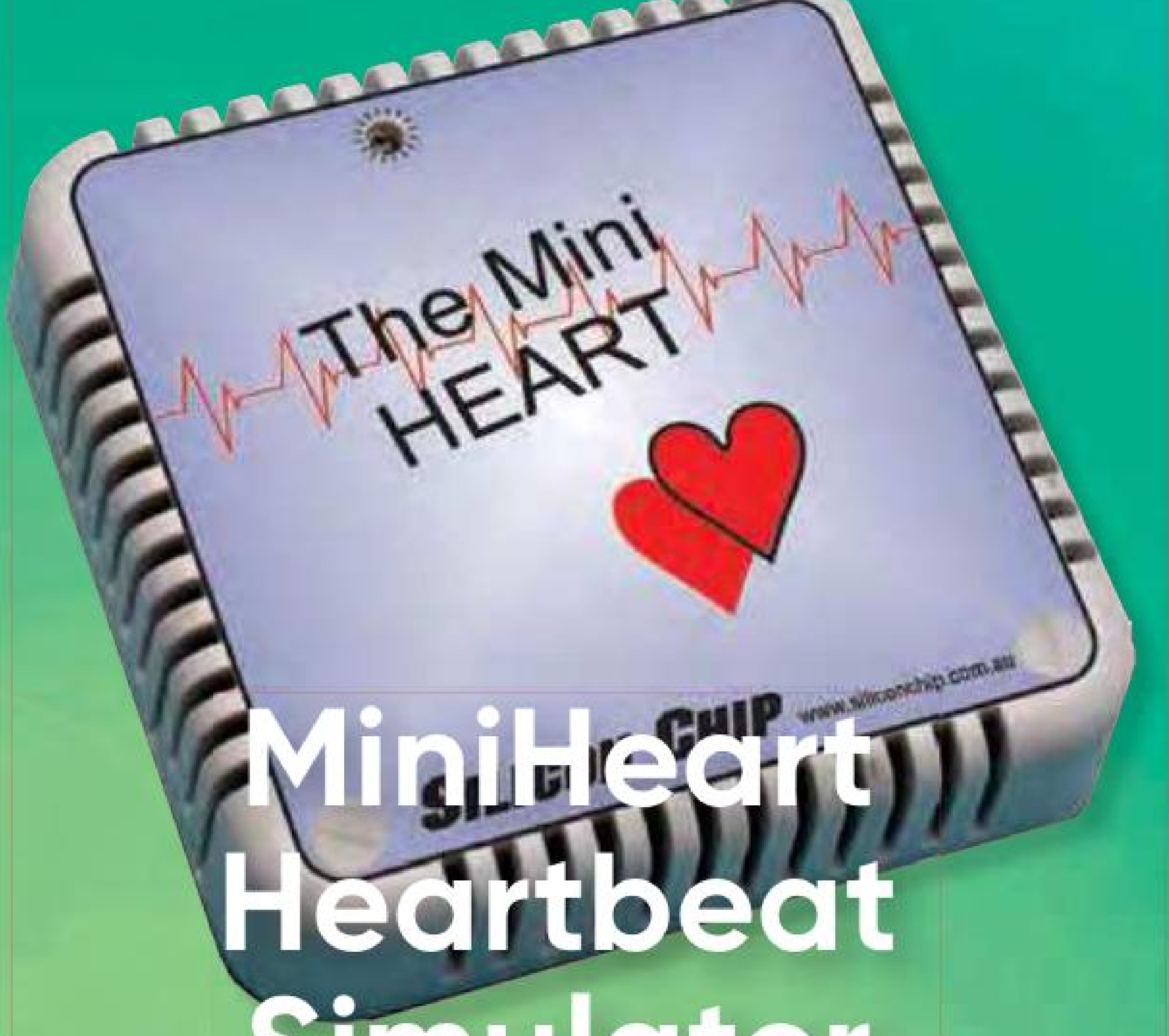

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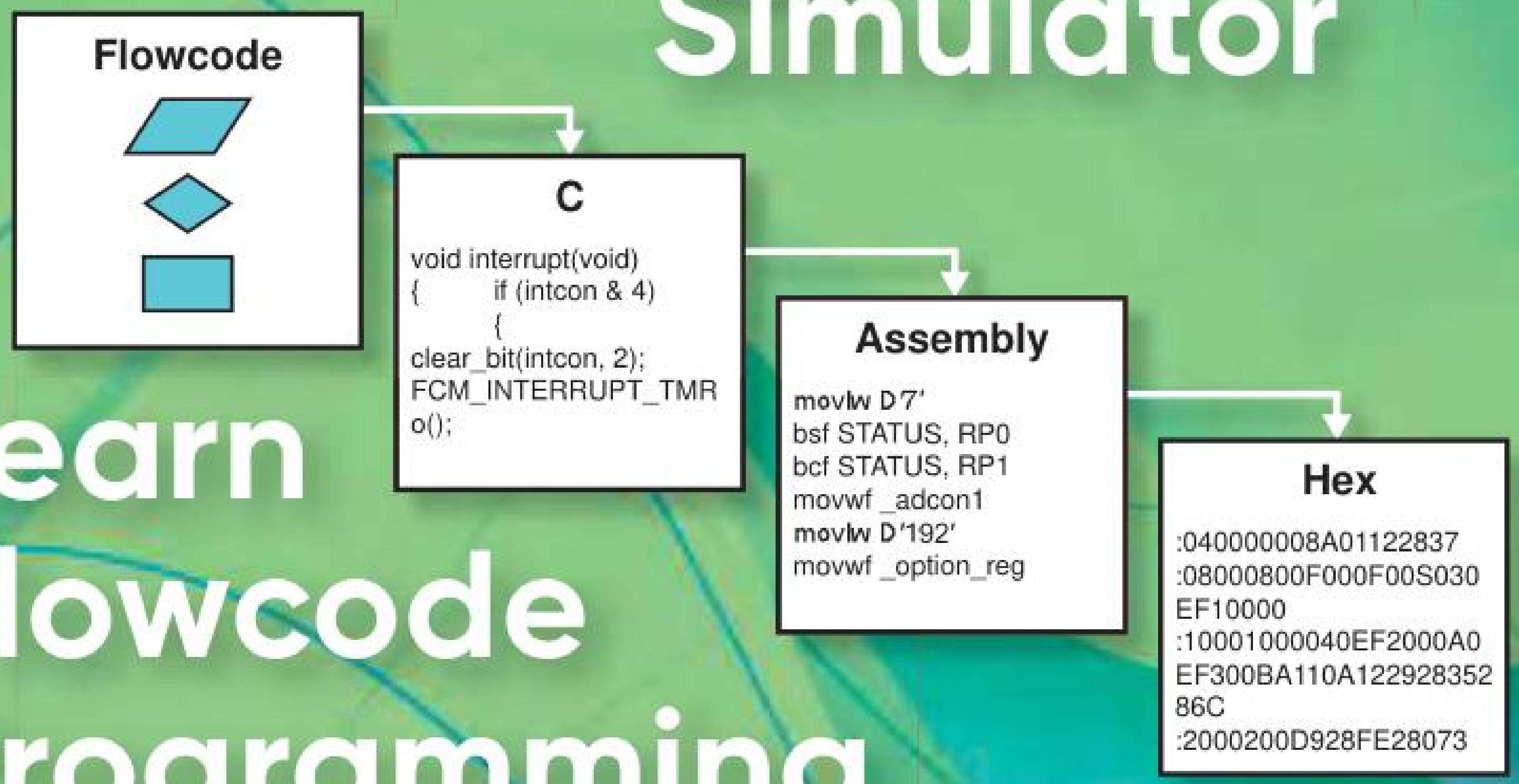

```
void interrupt(void)
{         if (intcon & 4)
          {
clear_bit(intcon, 2);
FCM_INTERRUPT_TMR
o();
```

```
movlw D'7'
bsf STATUS, RP0
bcf STATUS, RP1
movwf _adcon1
movlw D'192'
movwf _option_reg
```

```
:040000008A01122837
:08000800F000F00S030
EF10000
:10001000040EF2000A0
EF300BA110A122928352
86C
:2000200D928FE28073
```

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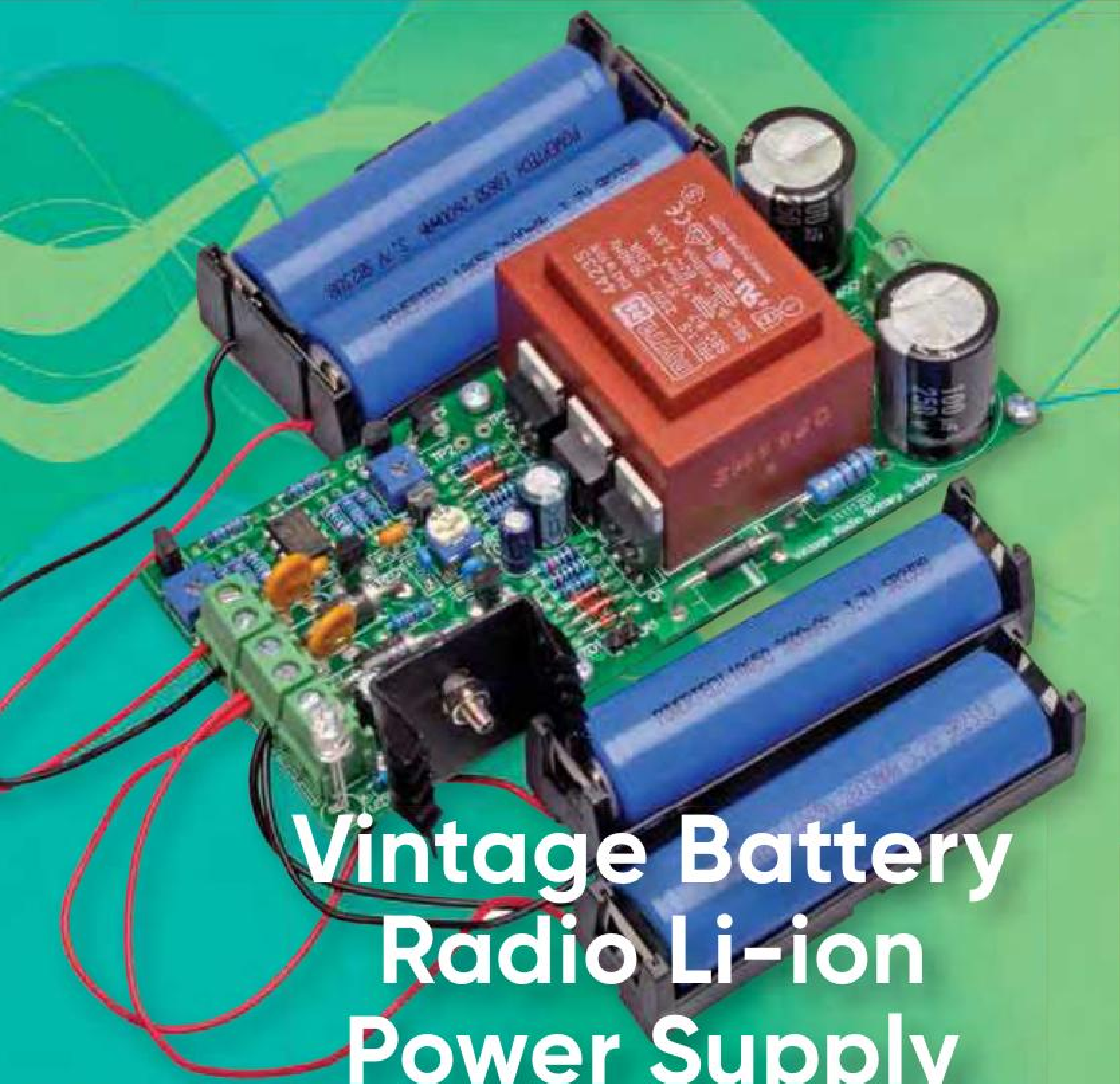

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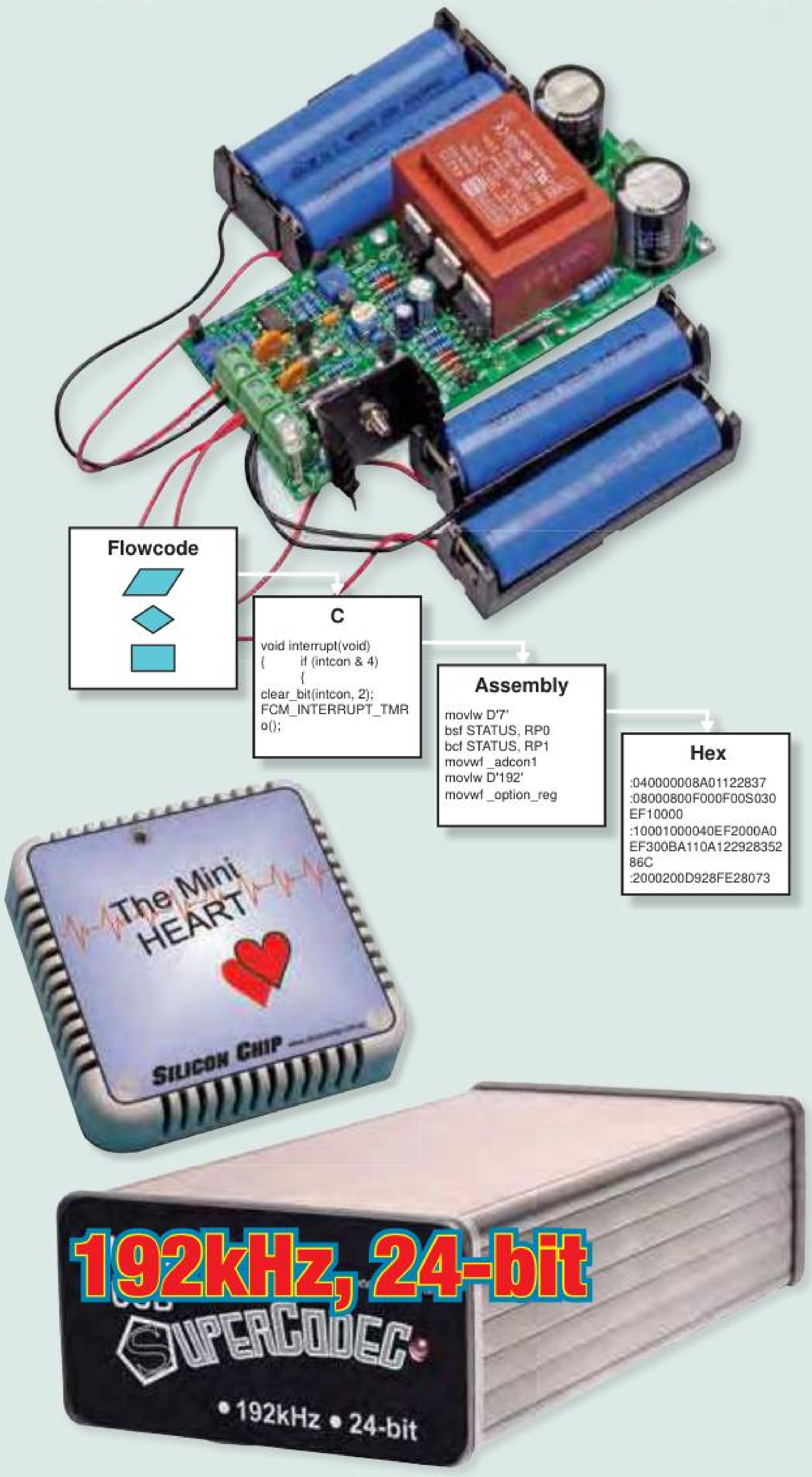
PIC18F DEV BOARD



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:08000800F000F00S030
EF10000
:10001000040EF2000A0
EF300BA110A122928352
86C
:2000200D928FE28073
```

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The February 2022 issue of *Practical Electronics* will be published on Thursday, 6 January 2022 – see page 72.

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The MiniHeart by John Clarke 24
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WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

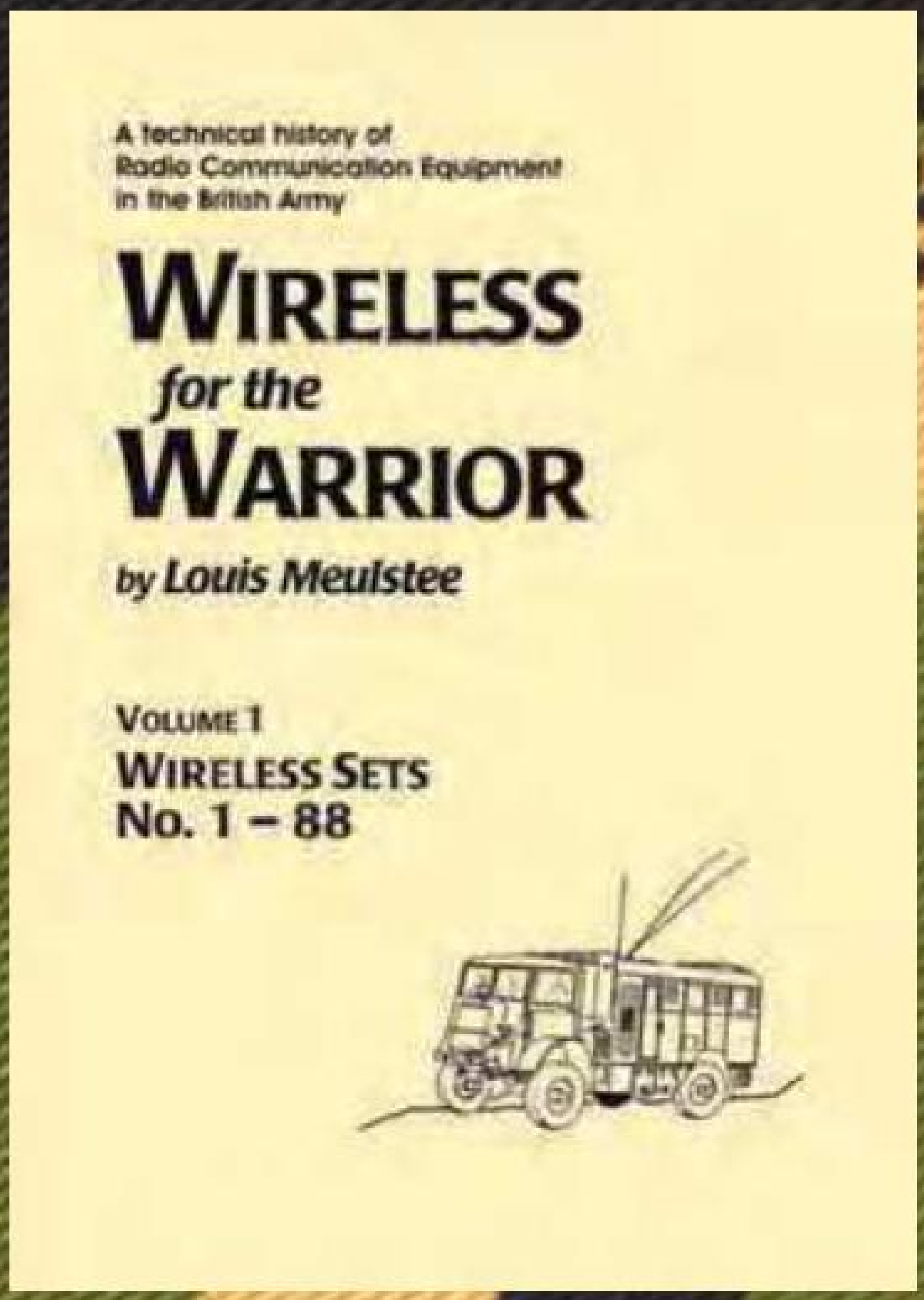
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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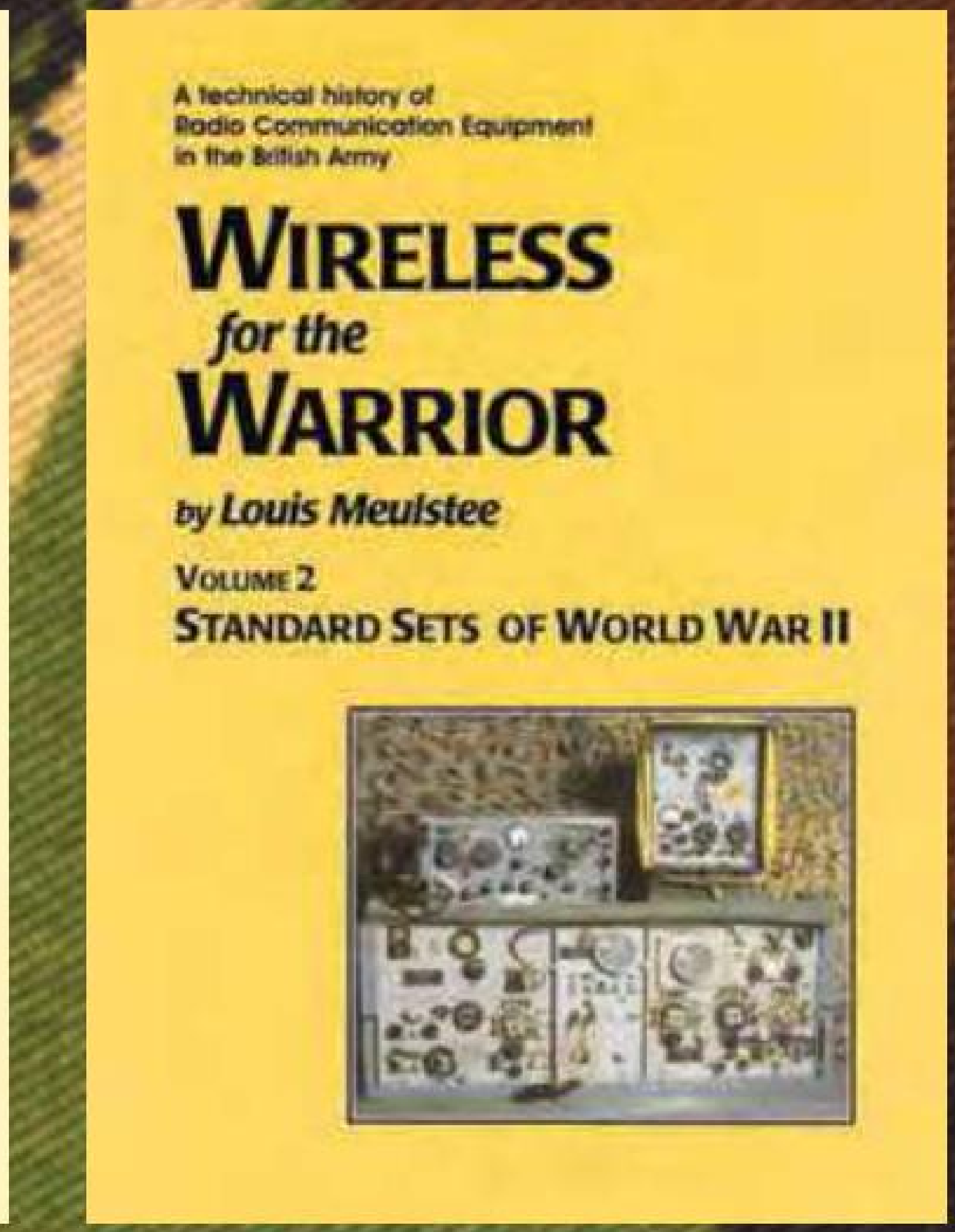

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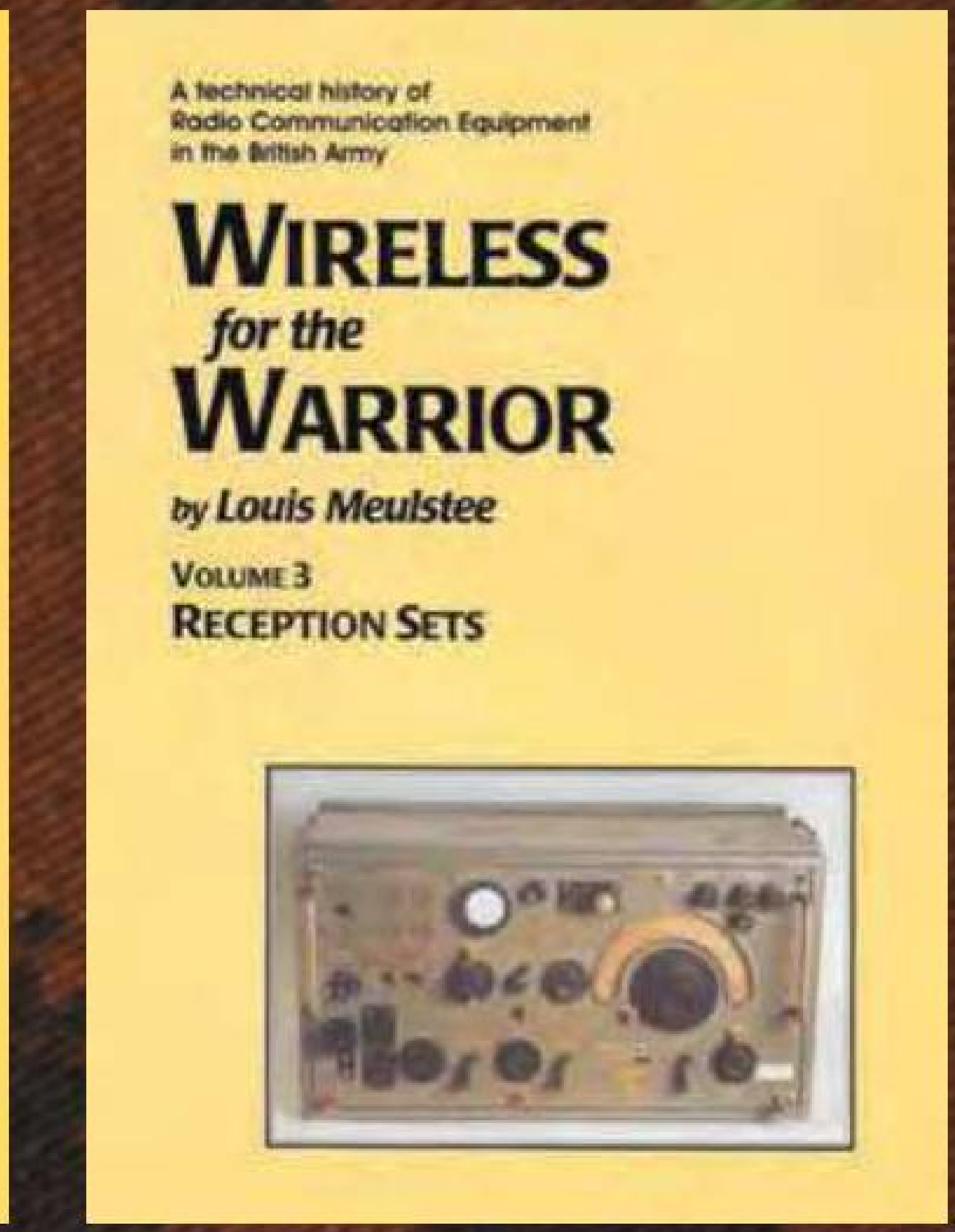

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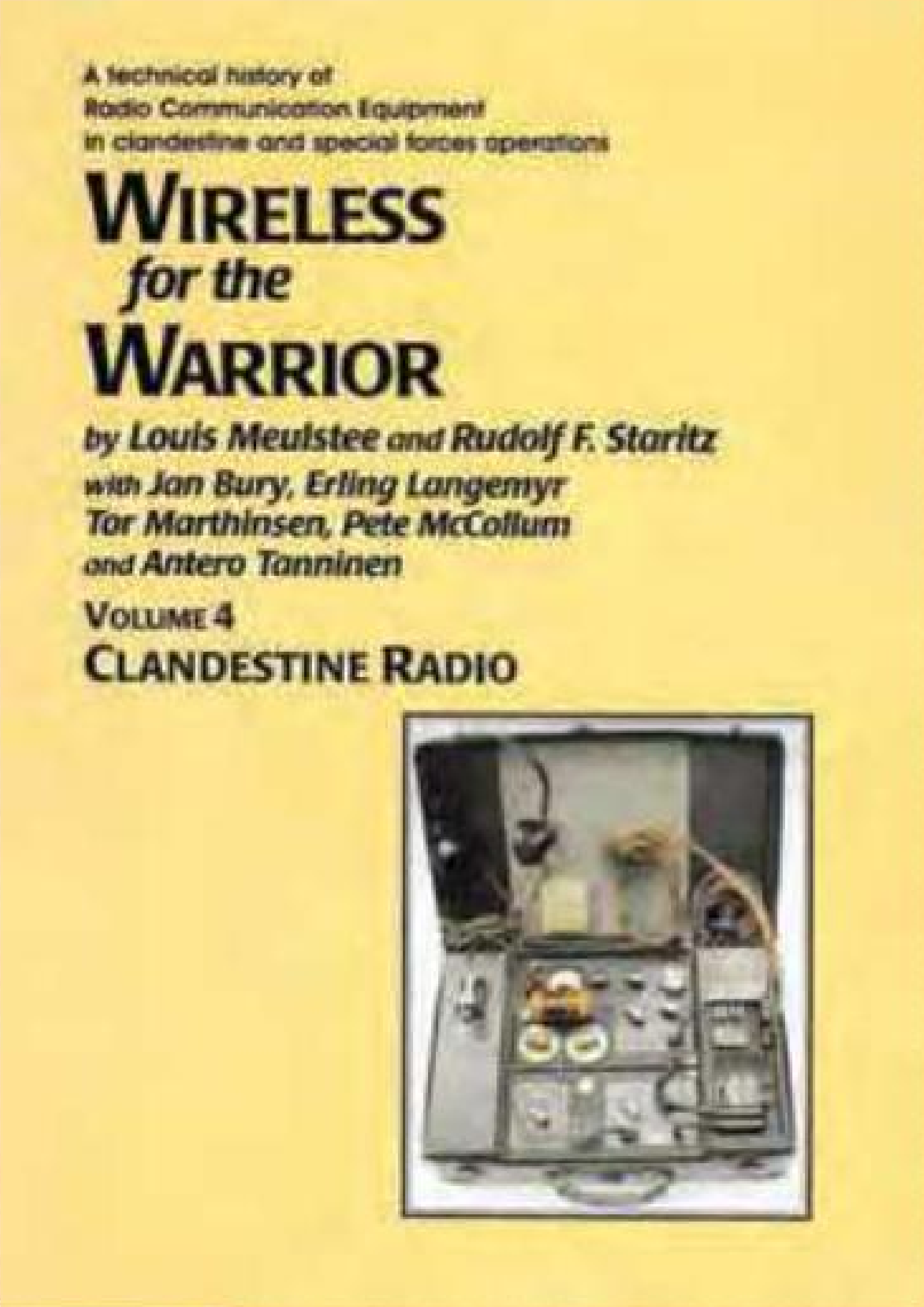

A technical history of
Radio Communication Equipment
in clandestine and special forces operations

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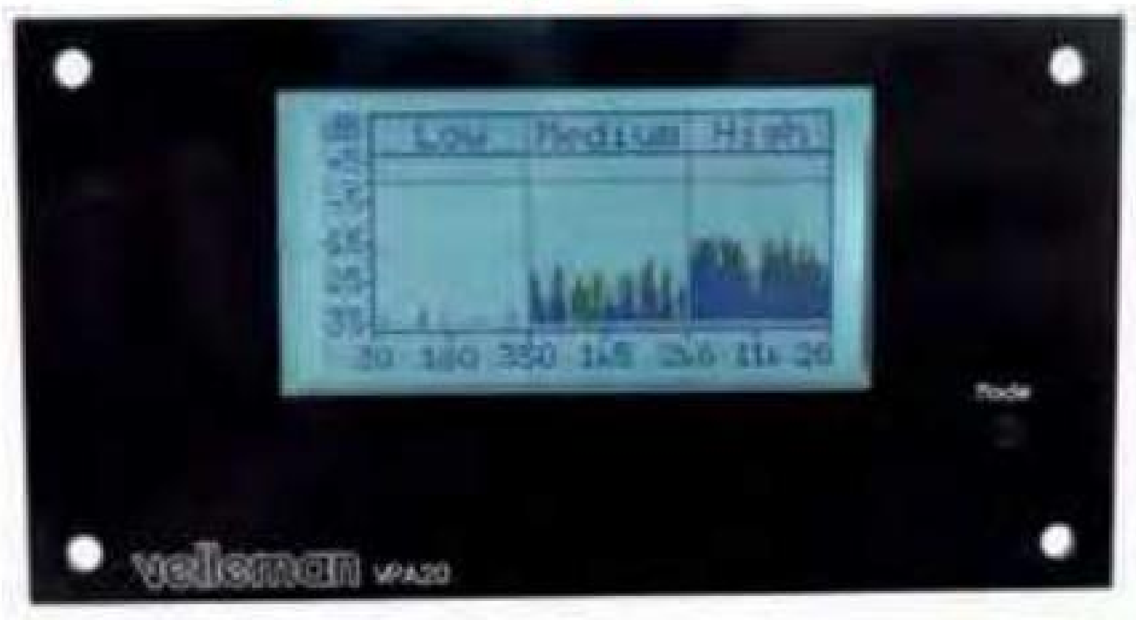

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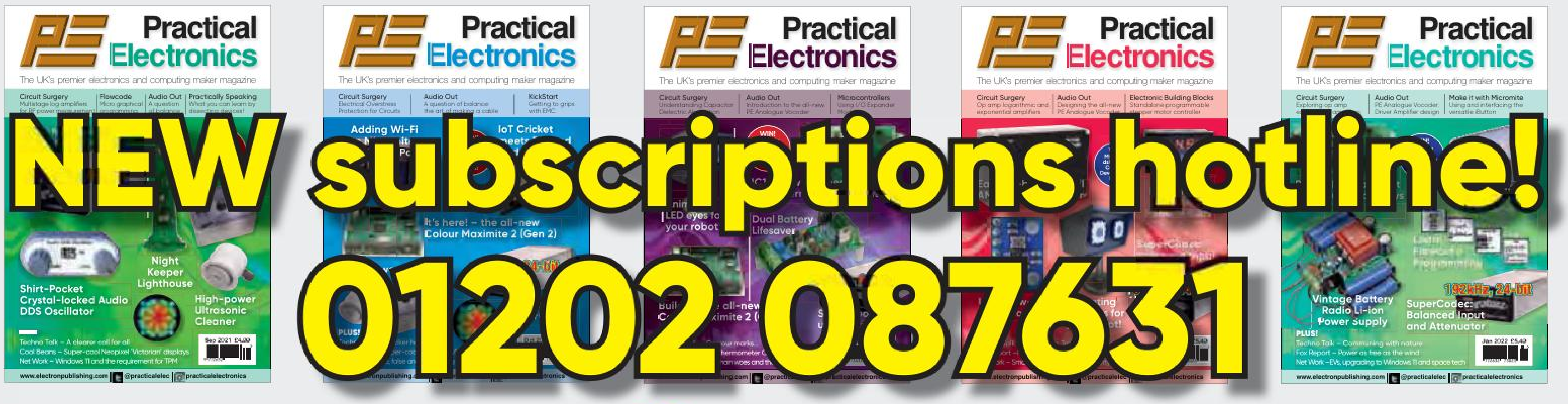

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2022 will be better!

Another strange year comes to an end, filled with the kind of news that makes you just want to turn off the TV, Internet and Radio. Let's hope 2022 is when we can really put the pandemic behind us, and life returns to some kind of normality. The wonders of modern drug design have really helped to turn the tide, but we're definitely not out of the woods yet, so let's be careful and considerate and make 2022 a better year.

Also, please remember it has been quite a rough ride for a lot of small businesses, so do support our advertisers who work so hard to keep our hobby alive.

Flowcode

This month, we start an exciting new series on Flowcode, a graphical programming environment that will get you up and running with PIC, Arduino and Raspberry Pi programming in no time at all. You can run it for free on a limited but still useful basis for as long as you want, and only make purchases when you are sure that it's right for you. Give it a try, I'm sure you'll be impressed and enjoy it.

Three cheers for the PE writers!

I've said it before, and I'll say it again, *Practical Electronics* is nothing without its loyal band of fantastic writers. They work very hard every month to bring you the best in original content. So, in absolutely no particular order – a great big 'thank you' to Alan Winstanley, Mike Tooley, Ian Bell, Mark Nelson, Mike Hibbett, Clive 'Max' Maxfield, Phil Boyce, Julian Edgar, Barry Fox and Jake Rothman. Also, a huge round of applause for the hard-working 'back-office boys', Stewart Kearn, Alan Winstanley and Kris Thain, who keep the shop and website ticking over.

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From all of us at *Practical Electronics*, thank you for your support over 2021, have a very happy Christmas and a healthy 2022!

Matt Pulzer
Publisher

The **Fox** Report

Barry Fox's technology column

Power as free as the wind

The world is going electric – electric cars, bikes, scooters, boilers and buses. Electricity can even produce hydrogen, to replace gas or petrol. But where will the electrons come from, if not from eco-unfriendly carbon-based fossil fuels such as oil, gas or coal?

Dare we risk another Chernobyl or Fukushima by proliferating nuclear power stations? And where to hide the radioactive waste? Solar panels only work during daytime hours, and less efficiently on dull days.

Wind turbines, however, ideally offshore where infrasound noise pollution is far less of an issue because there are no homes nearby, serve up clean, 'free' power for the majority of most days and nights. They do it throughout the year, every year, and especially well round islands such as Britain, which has been blessed with 45% of Europe's premium wind resource.

The 400MW Rampion 1 windfarm on the Sussex coast – Rampion 2 is planned to join it.

Rampion 1 and 2

The UK now has 39 offshore wind farms in operation, with 11 more under construction. Rampion 1, off Brighton, which has 116 turbines with 55m blades and a maximum tip height of 140m, was the first to be built along the UK's south coast. The turbines are spaced apart, with carefully calculated gaps for maximum aerodynamic efficiency, over 72 square kilometres (a bigger area than Guernsey) extending between 13km and 20km offshore.

Each turbine generates 3.45MW and the full farm has been feeding 400MW into the UK grid since November 2017 – equivalent to the electric power used annually by around 350,000 British homes, or half the homes in Sussex.

The overall owner is German company RWE Renewables, with its HQ in Essen, Germany. RWE says the cost of generating wind power has fallen by 66% in five years – as has happened with solar power costs.

RWE is now planning Rampion 2, also with 116 turbines, the same distance from shore (between 13-25km) but much larger blades (325m tip height) to increase power generation to around 1200MW and to serve over one million homes. The larger height will inevitably make the turbines more visible from the shore.

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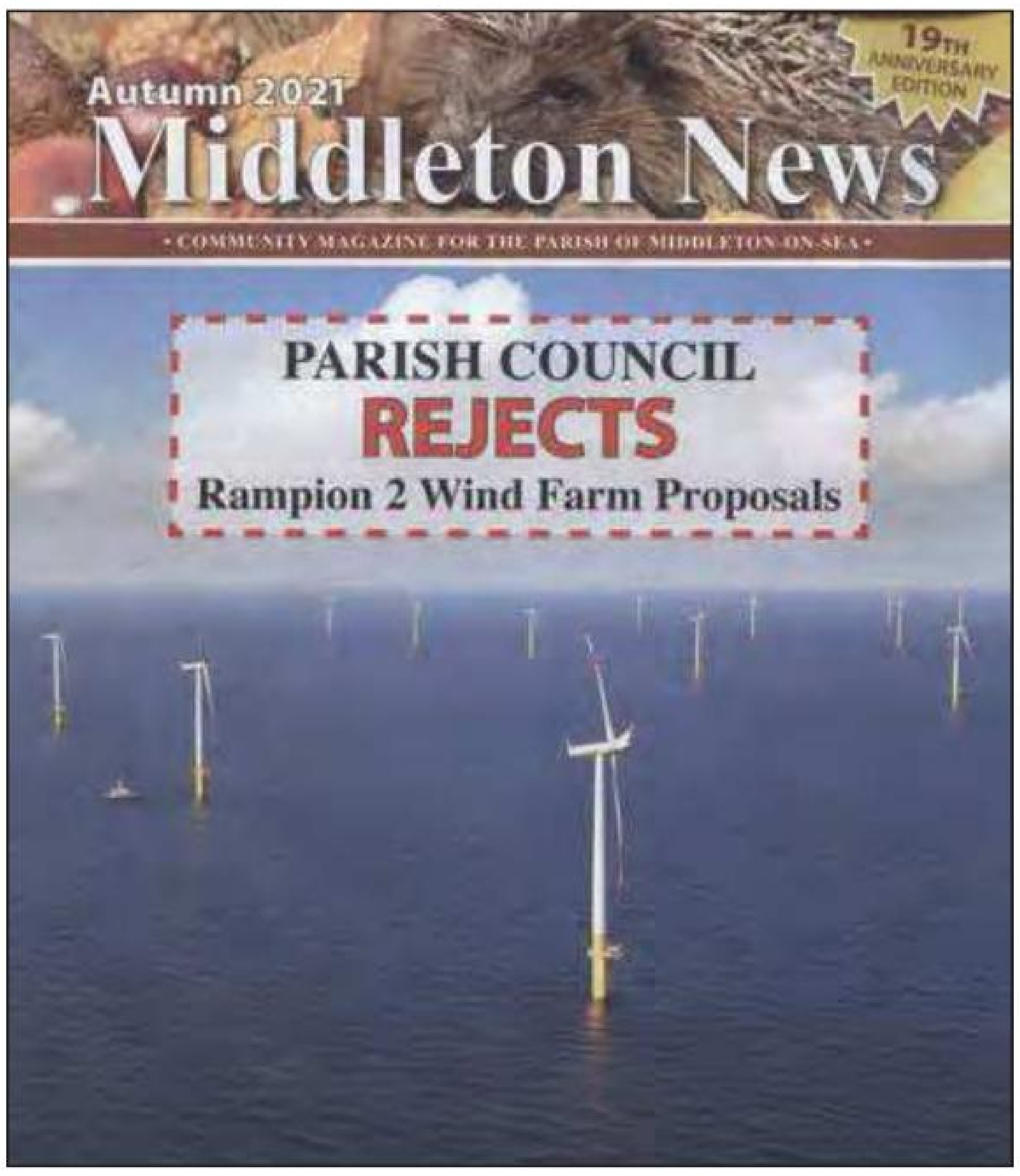

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PARISH COUNCIL

REJECTS

Rampion 2 Wind Farm Proposals

One example of how coastal towns are objecting to wind turbines, often on questionable grounds.

For and against

This has dramatically divided public opinion, especially in the coastal area around Bognor, which will be closest to the larger structures. Objectors in the area often preface their objections with the assurance that they are in favour of clean power from turbines and are 'not being Nimby' (Not In My Backyard), but want the turbines built somewhere away from their backyard view.

One objection is that the larger size and greater visibility will deter tourists. But numerous local charter boats now meet tourist demand for sightseeing trips out to the farm – see: **https://bit.ly/pe-jan22-ramp**

Objectors also claim that the erection of turbines compromises sea life. Talk to fishing boat operators along the coast and they will tell you the opposite; the exclusion zone around the existing turbines has created a marine sanctuary, with fish breeding profusely and now attracting dolphins which dine off their new free lunch. Sea kelp is re-growing because trawler pairs with drag nets can no longer scour the seabed near the turbines.

Another objection is that the wind is unreliable and the turbines would be better sited in the North Sea. RWE has found that power generation peaks at a wind speed of 27 mph and the blades only stop turning and generating power for 1% of the year – either because of no wind or storm speeds which would damage free-turning blades.

Eye evidence shows that even when beachline windsocks are hanging completely limp, the offshore turbines are moving healthily.

Objectors argue that the undersea cables which carry the power onshore, through the countryside and into the grid, will disfigure the landscape. But all cables are buried (under the seabed or under the countryside) and eye evidence from Hampstead Heath in North London shows how quickly Nature repairs trenching. Mains gas piping was buried across the Heath grassland and there is nothing now to see. Much more recently, dams were controversially built around the Heath ponds to counter the remote risk of catastrophic flooding. This devasted the Heath grassland, but it is hard now to see any signs of the work done.

Objectors call for the turbines to be built further out to sea, but this would increase power loss. For reasons of cost, aluminium rather than copper cables are used, with higher resistance. The output voltage from each turbine is 33kV, aggregated and upped to 150kV for the journey to shore. Longer runs inevitably mean more power lost.

Folklore rumours condemn the Rampion 2 turbines because they will be 'dark coloured'. RWE confirms they will be made from the same light grey fibreglass. There would be no point in painting them black, and it would be a never-ending 'Forth Bridge task' to keep them painted.

The new turbines (like the existing turbines) will have red tip lights at the top of the towers for aircraft safety. It's true, in clear weather they will be visible at night – because that is their purpose.

Whether this night sight, and the daytime view of the turbines offends as a blot on the seascape, or is soon visually ignored (like power pylons or telegraph poles) or appeals as a reminder that we are exploiting a clean and 'free' source of the energy on which civilisation now depends, is a matter of personal taste and opinion.

It will happen…

At a time when oil and gas prices are escalating, supply is hostage to international politics and global warming is accelerating, it becomes ever harder to hate the idea of a local clean source of power. But some people will doubtless do so. Realistically, given the current climate on climate change, the soaring cost of fossil fuels and nagging concern over nuclear plants, it is unlikely that any government will dare block Rampion 2 – and more developments like it. What parish councils, local newspapers and disgusted householders say will be duly noted, gratefully acknowledged and very likely simply ignored. Trying to communicate with RWE by email is a joke. The whole consultation exercise is probably a charade.

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…perhaps without the explosions

The high-profile PR skills of Joanna Lumley may make RWE take one issue more seriously. She has been campaigning to make turbine constructors more aware of the damage done to marine life hearing by detonating old WW2 bombs or mines found on the seabed ahead of pile-driving or cable trenching. RWE's Rampion exhibition centre on the seafront in Brighton is well worth a visit (it's free) but makes light fun of detonating the two bombs found ahead of Rampion 1 construction. Hopefully, if Rampion 2 gets the green light, Ms Lumley will win a more animal-friendly approach by, for example, burning out explosive chemicals rather than deliberately setting off underwater explosions: **www.stopseablasts.org/media**

Communing with nature

Techno Talk

Mark Nelson

Take equal measures of natural history and naturally occurring electronics, add a smidgeon of historical flashback, put these in the blender and what do you get? A remarkable revelation that certainly falls into the 'You could not make this up!' category.

Beginning in the late 1890s, Tesla (the inventor, not the car) spent more than ten years developing a means of generating and transmitting wire-free electrical power over long distance directly into homes and factories. In 1900, he expanded this notion to propose a 'World Wireless System' that could broadcast not only power but also information worldwide. Construction began a year later in New York state to build a large high-voltage wireless power station. Unfortunately, the money ran out before his ambitious new facility could be completed, and neither his miracle machine nor his global broadcasting system ever became reality. Knowledgeable as Tesla was, he had no idea that Mother Nature had already accomplished these feats biologically – in a manner of speaking, at least.

Nature's grid is global

'The ground beneath our feet, the entire globe, is electrically wired', states Nikhil Malvankar, assistant professor of molecular biophysics and biochemistry at the Microbial Science Institute at Yale's West Campus and senior author of a recent paper in the journal *Nature*. 'Previously hidden bacterial hairs are the molecular switch controlling the release of nanowires that make up nature's electrical grid.'

These nanowires exist on land and sea, permeating all oxygen-less soil and deep ocean beds to create a global web of bacteria-generated nanowires, he continues. A hair-like protein hidden inside the bacteria serves as a sort of on-off switch for nature's 'electricity grid'. But whereas the UK national grid delivers multi-purpose power, the natural nanowire grid performs only one function: to enable bacterial life to exist in the absence of air.

Snorkelling bugs

Almost all living things breathe oxygen to get rid of excess electrons when they convert nutrients into energy. Without access to oxygen, however, soil bacteria living deep under oceans or buried underground over billions of years have developed a way to respire by 'breathing minerals', like snorkelling, through tiny protein filaments called nanowires. Just how these soil bacteria use nanowires to exhale electricity, however, has remained a mystery to scientists until recently. The general belief was that the filaments were made up of a protein called 'pili' (Latin for 'hair') that many bacteria show on their surface.

However, in research published in 2019-20, a team at Yale led by Malvankar showed that nanowires are made of entirely different proteins. 'This was a surprise to everyone in the field, calling into question thousands of publications about pili,' he said. For the new study, two graduate students used cryo-electron microscopy to reveal that this pili structure is made up of two proteins, and instead of serving as nanowires themselves, pili remain hidden inside the bacteria and act like pistons, thrusting the nanowires into the environment. Previously, nobody had suspected such a structure.

The discovery is of far more than academic interest, naturally. Knowing how bacteria create nanowires will allow scientists to tailor bacteria to perform a host of functions – from combatting pathogenic infections or biohazard waste to creating living electrical circuits, the Yale team says. It will also assist scientists seeking to use bacteria to generate electricity, create biofuels, and even develop self-repairing electronics.

The biological WWW

Mother Nature has her own WWW, which she successfully constructed many aeons ago, without assistance from Sir Tim Berners-Lee, who invented the World Wide Web only in 1989. It was a British plant scientist, Merlin Sheldrake, who gave the biological WWW its ingenious name, calling it the 'wood-wide web' and popularising understanding that trees (and other plants) can share nutrients and they can warn each other of threats to their wellbeing. The possible existence of electro-biological communication between plants was first raised in 1988 (a year before the official WWW was invented) by another plant scientist, E.I. Newman, who argued that fungi could probably communicate with one another via their fungal root tissues, stating: 'If this phenomenon is widespread, it could have profound implications for the functioning of ecosystems'.

Multifunctional

Since then, research carried out by Sheldrake and others has positively proved the existence of these versatile networks just below the surface of the ground. In these unseen subterranean ecosystems, fungi act as facilitators to enable other plants to share nutrients such as nitrogen, sugar and phosphorus. Not only is the network an entirely mutual affair, with widespread inter-species communication, but it is also multifunctional. To explain this, I cannot do better than quote the *New Yorker* magazine, 'A dying tree might divest itself of its resources to the benefit of the community, for example, or a young seedling in a heavily shaded understorey might be supported with extra resources by its stronger neighbours. Even more remarkably, the network also allows plants to send one another warnings. A plant under attack from aphids can indicate to a nearby plant that it should raise its defensive response before the aphids reach it.'

Information transfer techniques

Although this 'other' WWW is fundamentally biological, it shares analogies and functions with familiar electronic principles, as two Wikipedia articles explain. The first – see: **https://bit.ly/pe-jan22-tt1** – states: 'The flux of nutrients and water through [fungal root] networks has been proposed to be driven by a source-sink model, where plants growing under conditions of relatively high resource availability (eg, high-light or high-nitrogen environments) transfer carbon or nutrients to plants located in less favourable conditions.' The other – see: **https://bit.ly/pe-jan22-tt2** – provides the electronic connection. 'Plants connected by a [fungal root] network have the ability to alter their behaviour based on the signals or cues they receive from other plants. These signals or cues can be biochemical, electrical, or can involve nutrient transfer.'

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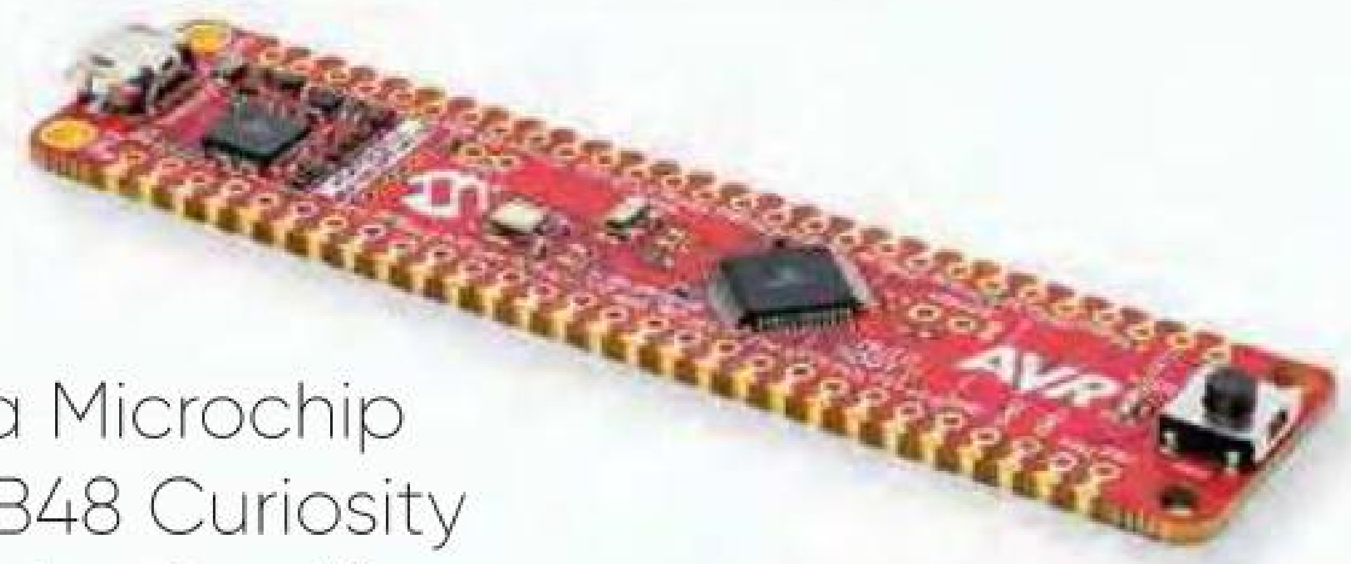

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Net Work

Alan Winstanley

This month's *Net Work* brings you the latest topical news about EVs, the 'fun' of upgrading to Windows 11 and updates on satellite and space technology.

In the past year, Net Work has covered some of the trends emerging in the electric vehicle (EV) sector, and the EV revolution shows no sign of abating. Thanks to CAD, modern microelectronics and rapidly developing battery technology, a dizzying range of futuristic-looking EVs is becoming available. However, their high initial purchase price is a hurdle for many buyers and Britain's impractical charging network is still lagging behind, which doubtless deters many motorists from buying an EV, no matter how 'green' their aspirations may be. Furthermore, the continuing shortage of semiconductor chips has impacted car production around the world, causing ongoing delays in the motor supply chain. In the UK, this shortage of new cars has seen a spike in used car prices, which in some cases exceeds the price of a new one. One Ford dealer said they had had no new cars to sell in three months, and that the production of one model had stopped entirely.

WLTP

Some of the EV jargon being bandied around was previously outlined in the December 2020 issue, which mentioned new EVs launched by MG Cars and Honda among others. With 'range anxiety' still in mind, manufacturers are moving towards improving the WLTP (Worldwide Harmonized Light Vehicles Test Procedure) rating by increasing efficiency and battery capacity, also reducing emissions and shortening the car's charging times. There is still plenty of life left in petrol and diesel vehicles though, but motorists will face some stark choices in coming years as travel becomes electric-powered, and drivers may have to plan their journeys differently. In Britain, long-distance trips might mean factoring in a coffee break or two along the way while your car charges up, and drivers will ponder the kW ratings of chargers – if they can find one. The driving range is also affected by weather and the frugality of the driver, but no doubt EV chargers will gradually become the norm at filling stations, and petrol pumps will be relegated to second place.

The ZipCharge Go offers a user-friendly top-up of electric vehicles. It is controlled by an app and has many security features.

Charging options

Other charger options are starting to spring up: an interesting new semi-portable charger for electric vehicles called the ZipCharge Go was unveiled at the COP26 UN Climate Change conference held in Glasgow last month. The ZipCharge Go is effectively a powerbank for EVs and promises a quick 20-40-mile top-up charge delivered in 30-60 minutes, they say. It has a user-friendly rolling suitcase style of form factor and, of course, there is a smartphone app to manage it. The product looks to be quite 'nickable,' so I enquired about its security features: the designers say the charger can only be authenticated by its owner through the app and charging can be switched on and off remotely or disabled altogether as one would with a stolen mobile device. The cable itself is locked in situ to the charger and the car. As for the batteries, they are welded in place and the bespoke electronics have no second-hand value. A battery replacement guarantee will be offered if they are stolen while on charge in public places. ZipCharge Go is still in R&D, with a likely launch date at the end of 2022. More details at: **www.zipcharge.global**

Massachusetts-based startup Sparkcharge is taking a different approach in the US by offering mobile on-demand charging for EVs. Unlike the ZipCharge Go, Sparkcharge operates through a network of service providers and its rugged 'Roadie' battery system claims to offer 'a mile [of driving] for a minute of charging'. More details are at: **www.sparkcharge.io**

NIO Logic

On the EV front, MG Cars, the British sports car brand now owned by China's state-owned SAIC Motor (see *Net Work*, December 2020 and January 2021) has started to refresh its range of EVs coupled to a fresh TV campaign. The revised MG ZS EV has a 72.6kWh, water-cooled lithium-ion battery and a claimed range of [up to] 273 miles. This electric SUV still costs the best part of

The Sparkcharge 'Roadie' provides kerbside EV charging through a network of service agents in the US.

NIO Power Swap in action: a NIO EV battery is automatically swapped out for a newly charged one. (Image: YouTube/ Crossing China)

£30,000 though, which is not exactly trivial. More details of UK-spec cars at: **www.mg.co.uk/new-cars/new-mg-zs-ev**

SAIC clearly understands the value of brand awareness to consumers. More competition in the EV market is waiting in the wings: after a rocky financial start the Chinese brand NIO, so far largely unheard of in Europe, now has global ambitions after receiving state investment and is carefully scoping the EV market beyond China (see *Net Work*, April 2021, p.14). This upcoming EV maker takes the idea of 'thinking outside the box' to a whole new dimension. NIO is happy to play the long game, recognising the need to develop brand awareness and customer loyalty in the minds of European buyers, implied NIO's President Lihong Qi in an *Automotive News* report last year. NIO chose Norway as a bridgehead before entering mainland Europe. Norway has an extremely high uptake of electric vehicle sales, with more than 90% of cars sold in September 2021 being electric or hybrid, helped by Norwegian EV-friendly tax concessions.

Power Swap – the fastest 'charge'

Apart from offering high-tech home chargers for their cars (the slimmest DC chargers in the world, they claim), NIO cars have one major feature that's currently missing on other electric vehicles: 'battery swap' technology, which NIO calls 'Power Swap'. The technology is truly mind-boggling: simply drive into a Power Swap station, a bit like visiting a tyre bay. The car more or less parks itself automatically, and the car's battery is swapped robotically for a fully charged one in just three minutes. Plans for NIO's first Power Swap station near Oslo have reportedly already been approved.

Each station has nearly 240 sensors and multiple cloud computing platforms that recognise the vehicle, handling the entire process while the driver remains seated. Over 300 battery swap-outs can be handled per day this way, they claim, and NIO plans to build 5,000 such stations in China as a joint venture with China's Sinopec fuel producer. More examples of NIO's adventurous approach include the provision of mobile chargers built into a fleet of service vans that will offer NIO cars a 10-minute boost and 100km range. An on-demand 'valet charging service,' where a valet takes your NIO car away to be charged, has also been advertised. Smartphone helper apps are also heavily integrated into NIO's ecosystem.

One possibility (or aspiration) is that all EV batteries could become interchangeable, and drivers could just queue up for another one regardless of the make of car. It would make getting a battery swap as routine as using a car wash. As NIO starts to learn from its Norwegian experience, time will tell whether the marque and the Power Swap battery-swapping system is viable enough to expand into other EU countries.

A NIO owner shared his experiences of the first version of NIO's battery swapping system in a YouTube video a year ago: **https://youtu.be/0StTrsdoD3c**. How NIO's latest version of its 'Battery as a Service' works in practice is showcased in their promo at: **https://youtu.be/aBdQQxgxDrY** – plus a driver's eye view of this new system is at: **https://youtu.be/EvMr42VnFyo** (Details of NIO's range can be found at: **www.nio.com**)

Battery recycling

What will happen when an EV reaches its end of life? No doubt the EV revolution will eventually cause a sea-change in the demand for spare parts and material recycling. Car scrap yards of the future will probably look nothing like the oily, teetering heaps of rusting metal that we've all seen in the past. In Britain, the motor dismantling trade has cleaned up its act considerably in recent years, and sourcing used parts online means that it's no longer necessary to tramp round a breaker's yards searching for a reclaimed drive shaft or gearbox for our fossil-fuelled cars. Websites such as **www.breakerlink.com** save lots of legwork and can source quotes for used car spares from breakers' yards. A few years ago, I needed a replacement car headlight and was deluged with offers this way.

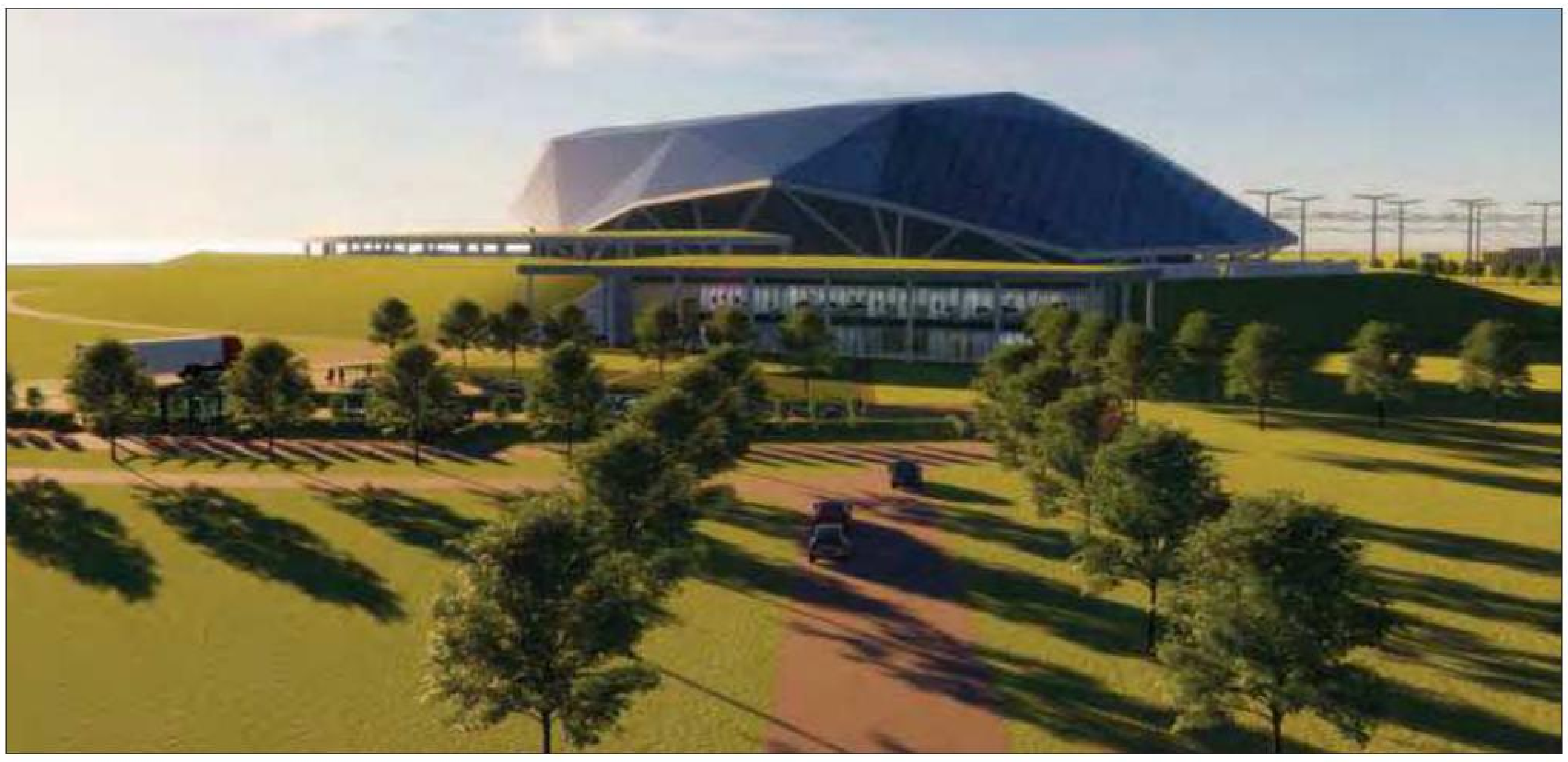
America had a head start on EV sales as Tesla has produced all-electric cars for a dozen years, starting with the Tesla Roadster based, ironically enough, on the chassis of the British Lotus Elise sports car. Readers might recall Elon Musk launching one into space, with his Starman manikin at the wheel (*Net Work*, September 2019). Incidentally, the car's current location is shown at: **www.whereisroadster.com**

With scrap yards in mind, interested readers might like the work of Rich Benoit (a.k.a. 'Dr Tesla Frankenstein') who specialises in salvaging parts from Tesla cars or rebuilding them from scrap. His skills are remarkable; a video at **https://youtu.be/NuAMczraBIM** shows his dedication to recycling, not scrapping.

The Cat's away

I wrote back in the March issue how China's Great Wall Motor (GWM), the country's largest maker of pickup trucks, had an ill-starred foray into the UK market some years ago. Their rugged pick-ups found favour with some of Britain's farmers for a time, but the engines couldn't meet new emission tests, parts were hard to get and the brand quietly disappeared. GWM is pinning its latest hopes on a very stylish all-new EV to be sold under their Ora brand. Known locally as the 'Haomao' (Mandarin for 'Good Cat'), the car is destined for Britain soon and will be called the Ora Cat 01. Its cutesy retro style apes several popular cars like the MINI and, by EV standards, Ora is not pussy footing around with its UK sales drive. The car will be very aggressively priced

Coming to UK shores is the retro-style Haomao 'Great Cat' EV from Great Wall's Ora brand. Might their Heimao 'Black Cat' challenge the Honda 'e' in the future?



An impression of a compact nuclear power station based around Rolls-Royce's small modular reactor or SMR. (Image: Rolls-Royce Group)

(about £25,000) and is unashamedly designed to take a bite out of major European EV car sales. More details are at: **https://uk.ora-eu.com**

Meanwhile, on the GWM global website at **https://bit.ly/pe-jan22-gwm** I spotted the Ora Heimao R1 or 'Black Cat' which has taken some styling cues from the expensive but funky Honda 'e' city car (*Net Work*, December 2020). Perhaps sales will follow in the Good Cat's tracks. While we're on the subject, for an eye-opening view of GWM's firepower, take a look at their 2020 sales report at: **https://bit.ly/pe-jan22-gwm2**

Sourcing the juice

Despite all these futuristic 'zero-emission' vehicles heading our way, the slow roll-out of Britain's EV charging network has yet to inspire much confidence, and the precarious state of the UK (if not European) electricity generation network is finely balanced as well. Early adopters of EVs will get to learn about their car's real-life range in typical British weather conditions, how long the batteries will last in service and how expensive they will be to replace, assuming it's possible to replace them at all. The upsurge in EVs is likely to constrain battery supplies as well. In England, major lithium deposits have been found by geothermal engineers in Cornwall, with 4,000 tonnes potentially being extracted annually in the future, see **https://bit.ly/pe-jan22-li** which may eventually help meet the insatiable demand globally for batteries of all shapes and sizes.

The overarching question is, of course, how will all this 'extra' electricity demand be met in the first place? In Britain, an option that is taking shape is the small modular reactor (SMR), a concept that has been floated for some years. This is a compact nuclear-powered generation plant that promises lower construction costs and faster turnaround compared with the construction of traditional nuclear power stations. The clever modular construction could be 80% British-made and would have a truly massive export potential. Ninety percent of the power plant would be made on production lines and then shipped by road or air for assembly and commissioning on site; one 470MW SMR would have a footprint the size of just two football pitches. The UK Government is helping to kickstart the concept by investing £210m ($275m) in Rolls-Royce Group, which has produced nuclear power plant for Britain's submarine fleet since the 1950s. A further £250m has been raised privately to take the feasibility study forward. The distinctive shape of an SMR power station may become a familiar sight on our landscape within a decade. Learn more at **https://www.rolls-royce-smr.com/**

Stuck in the middle with Windows 11

My thanks to long-term *PE* reader Dave Bancroft, who writes: 'I bought the very first issue of *Practical Electronics* that included how to make your own bass guitar in the Autumn of 1964, and the next issue, and the next. It was a dent in my pocket money, but I treasured every issue! I've read your *Net Work* articles for many years and your article in the September issue about upgrading a PC to Windows 11 set me looking more deeply into something I've uncovered in my PC. I have a three-year old, average Windows desktop made by HP, with a 3.00GHz i5-7400 CPU, 16GB RAM, 1TB+ of SSD storage… etc. I have faithfully kept up with all the Windows 10 Pro updates. Recently, Windows Update has started telling me: "You're up to date" followed by "This PC doesn't currently meet all the system requirements for Windows 11."

'I followed the Microsoft link supplied to install and run their "PC Health Check," which confirmed that the PC supports Secure Boot, it has TPM [Trusted Platform Module] 2.0 enabled and there is at least 4GB of system memory (RAM). Then came the bad news: "The processor isn't currently supported for Windows 11."

'Delving into the Intel portion of the fully supported CPU list for Windows 11 (see: **https://bit.ly/pe-jan22-W11A**) I eventually found the Intel Core i5 section of the rather long list, I see that there is a range of CPU number suffixes from i5-10200H to i5-11600T inclusive, then a second range from i5-8200Y to i5-9600T. My CPU subtype, i5-7400 is a "lower" number and, most importantly, was absent from the list! No doubt this is what has triggered the incompatible-CPU error message.

'I went round in futile circles trying to get answers from Microsoft before I finally got some sense from HP themselves. They confirmed that my Intel i5-7400 CPU is not some stunted, semi-crippled OEM version, but a perfectly valid candidate for Windows 11 compatibility. HP Sales added that it's an ongoing evolving situation and not to worry too much, because if this illogical incompatibility situation persisted, millions of people would be affected and something would get done to fix it, really quickly.'

By co-incidence, Dave's email arrived just as I was checking two of my own W10 PCs. Windows Update can be accessed easily by hitting the Windows key and typing 'Update'. A pop-up about Windows 11 may appear automatically. You can also type Winkey then 'System' to view your PC's system data. On my older machine I experienced exactly the same thing as Dave, with Microsoft's PC Health Check app citing the lowly CPU spec as incompatible, and, like Dave, I was a bit irked to be told that this PC might not be a candidate for Windows 11.

I ran Microsoft's Health Check app on my recent home-brew PC and it complained about the lack of TPM 2.0. Here's another tip: type `tpm.msc` after hitting Winkey and the TPM Management Console will open: again, my PC claimed (hopefully erroneously) that a TPM could not be found on my computer even though it has a Secure Boot option and the Asus motherboard webpage clearly states that mine is 'Windows 11 Ready'. Asus has checked W11 compatibility across their range and it's probable that my PC will be upgradeable. Sometimes, a BIOS update may be needed first, and/or the BIOS settings may need altering to make a system W11 compliant. It's worth checking

SpaceX Starships ready for tests – future Starships are destined to transport people to the moon and possibly Mars. (Image: SpaceX)

your PC or motherboard maker's website for up-to-date news and, as Dave found, we can expect a lot of conflicting advice about Windows 11 compatibility before the dust finally settles. A brand-new Asus Windows 10 notebook immediately offered to upgrade to Windows 11 during setting up – but, until I know more, I declined the update, at least for now.

The web is alive with Windows 11 tips and workarounds, and one final option might be to 'force' a Windows 11 installation using the classic media creation tool, or create an ISO image. The place to start is **https://bit.ly/pe-jan22-W11B**

If the host PC is supposedly incompatible, it's not clear whether such Windows 11 installations will enjoy future security updates though. Good luck!

The James Webb Space Telescope ensconced inside the cleanroom at its launch site at Guiana Space Center, prior to assembling into an ESA Ariane 5 launcher. (Image credit: NASA/Chris Gunn)

A satellite state

The Rwanda Space Agency has submitted plans to build two satellite constellations to deliver broadband under its 'Cinnamon' project, comprising nearly 330,000 – a third of a million – CubeSats operating in LEO (low earth orbit). A CubeSat (see *Net Work* October 2020, p13) has a tiny form factor and at 1U is just 10 × 10 × 10cm. Sources claim that following approval, the network could be built in three years.

Rwanda has a troubled history in bringing broadband services to the country. Early hopes were pinned on satcomms firm OneWeb before it was made bankrupt and then rescued by the UK Government and India's Bharti Global. Who is behind Rwanda's latest ambitions is less clear, but sources claim the project's being masterminded by Greg Wyler, the original founder of OneWeb and someone with a long history of working in Rwanda's telecoms sector.

London-based OneWeb is going from strength to strength and is now partnering with the UK's British Telecom (BT) Group to deliver space-based broadband services to less accessible areas of the UK. I can think of at least one family friend, marooned in Scotland who depends on archaic, windswept copper wires for ADSL2 or FTTP (no-one seems to know), who would benefit from such a satellite-based system.

Meantime, Boeing has plans of its own and intends to build a small fleet of about 150 satellites, while Amazon's Project Kuiper satcomms network of 3,200 satellites is slowly limbering up, with launches of prototype satellites expected in late 2022. Astra, the American satellite launching company, is entering the fray and has filed its own plans for launching an array of 13,600 broadband satellites into LEO.

Latest SpaceX news

Readers might recall my mention of the diminutive 'SpaceBEE' CubeSats proposed by Swarm Technologies for handling IoT data (see photo, *Net Work*, October 2020 p.14). These tiny (¼U) satellites fit in the palm of your hand and will carry data for connected cars, agriculture and marine applications, and earlier this year Swarm became a wholly owned subsidiary of SpaceX.

There was a time when almost every rocket launch was celebrated as a marvellous spectacle, but they have fast become routine events, with SpaceX showing how it's possible to lob 60 satellites at a time into space and recover the spent launchers for re-use afterwards. Technical filings highlight tension between the main satellite operators who are worried about the risk of collisions and the possibility of interference across various wavebands that their relentless drive for LEO satcomms networks may cause.

Space enthusiasts are eagerly eyeing the next SpaceX milestone: the SN20 (Serial Number 20) Starship powered by a Super Heavy rocket stage. The prototype fired some of its Raptor engines for the first time in October. SpaceX's Starship has been chosen by NASA's Artemis program to propel men and women to the moon and possibly beyond. YouTube is full of SpaceX videos and commentaries, but **https://youtu.be/TeVbYCIFVa8** gives an insight of the Starship taking shape. Future ambitions of SpaceX include landing on Mars and building a sustainable base there. This could be entirely possible in years to come, and you can see more about their Mars-bound program at: **https://bit.ly/pe-jan22-spx**

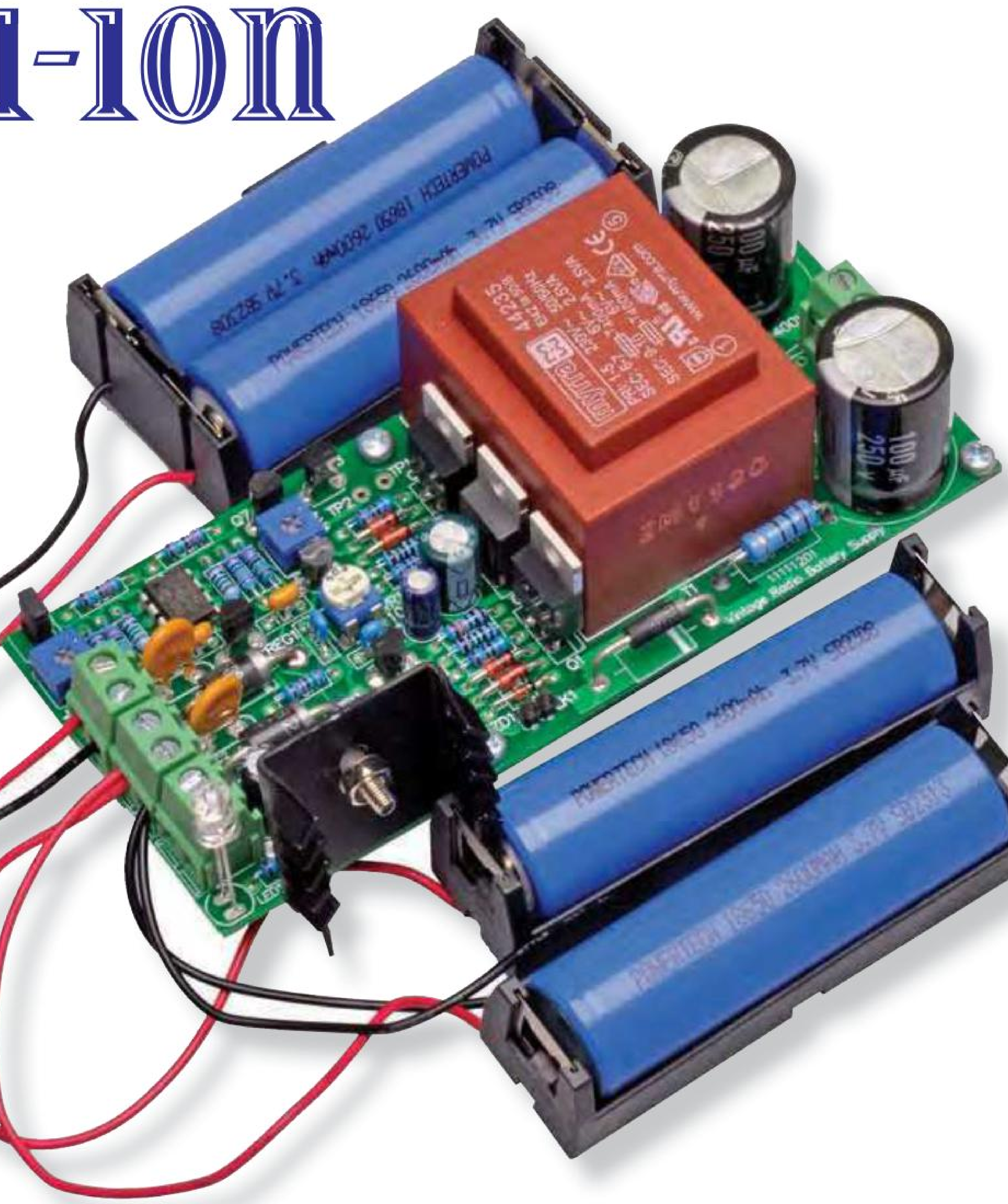
Last, this month, another ambitious project is fast coming together in the form of the James Webb Space Telescope (JWST), described as the world's largest and most complex space science observatory ever built. The telescope is an international effort and is destined to launch from French Guiana in mid-December. As the space observatory starts to explore the deepest mysteries of the cosmos, readers will hear a lot about new discoveries and mention of the 'James Webb telescope' will become as commonplace as 'Hubble' used to be, so rest assured I'll be covering progress in future columns.

That's this month's roundup of news from *Net Work* – enjoy the Christmas festivities wherever you are, and join us next month!

The author can be reached at:
alan@epemag.net

Vintage Battery Radio Li-ion Power Supply

by
Ken Kranz
and
Nicholas Vinen



Vintage Radio enthusiasts know that 'A' and 'B' batteries have been effectively unobtainable for some time. So what to do? Try this compact and easy-to-build module. Using Li-ion or LiPo cells, it can generate both the A and B supplies for most battery valve sets, and it suits sets with a wide range of HT voltages. It generates virtually no EMI (which could interfere with radio reception). It also incorporates battery over-discharge protection and reversed battery/cell protection.

I wanted a power supply to run a typical battery-powered vintage radio from a set of 18650 (or similar) Li-Ion rechargeable cells. I considered developing a switchmode design for decent efficiency, but RFI from switchmode supplies can interfere with radio reception.

So I designed this 'low-tech' supply using a low-cost PCB-mounting transformer and a few transistors and passive devices instead.

This circuit was designed to power my Aristocrat Tecnico 859 from four 18650 Li-ion cells, but it would suit a great many valve sets. It is often tuned to 3WV in Victoria's Wimmera from my home in Adelaide, South Australia, with no power supply noise evident. The set requires 90V for the 'B' supply and also 1.4V for the 'A' supply.

One of these was also fitted to a 1937 Velco radio that I restored, although I left off all the low-voltage cutout components as the set now runs from a 6V DC plugpack.

The filament supply is 2V @ 700mA, so I attached the low tension (LT) regulator to the diecast aluminium enclosure the PCB is fitted into. The B+ for this radio is 135V.

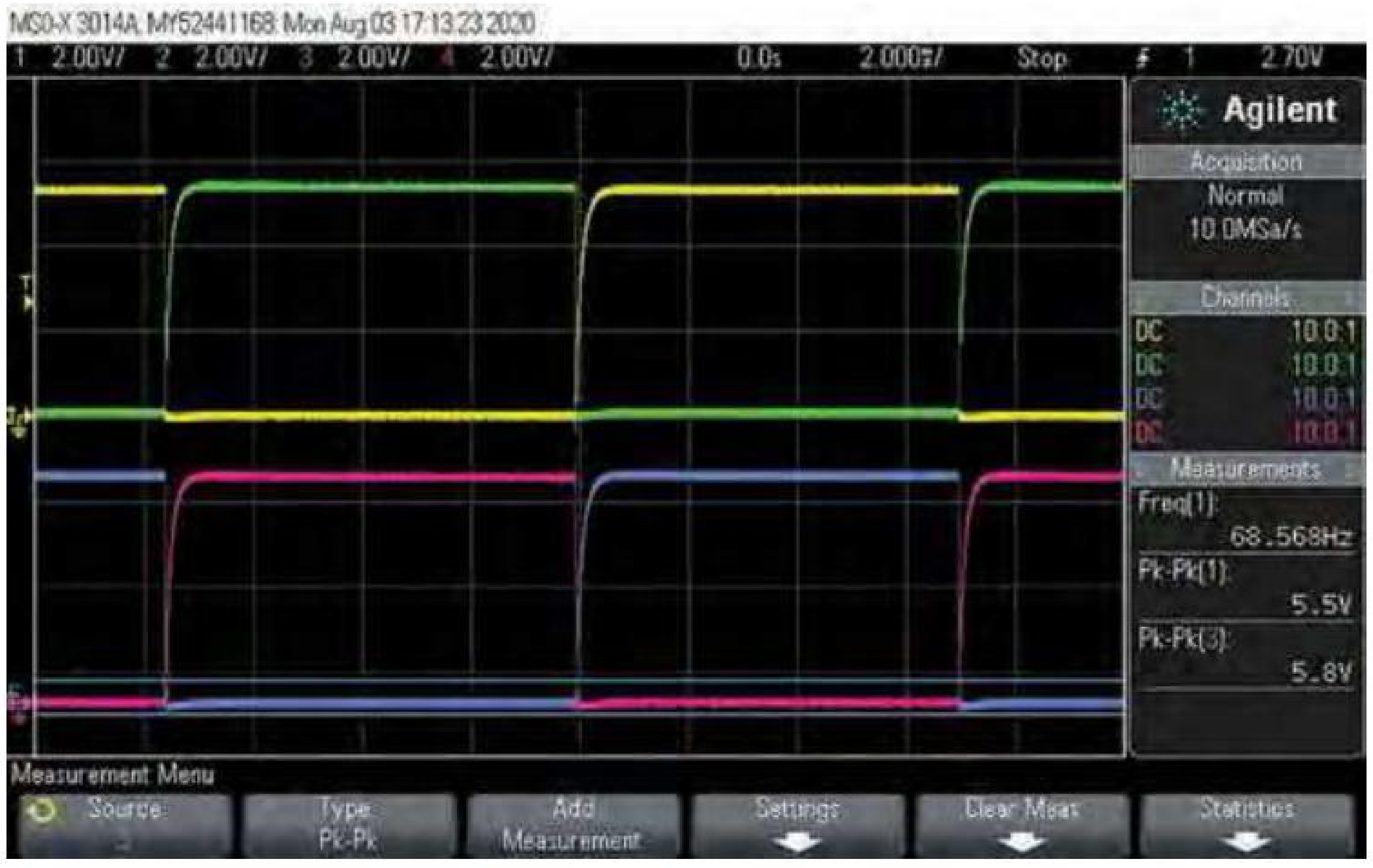
Most battery-powered radios need a B+ supply of 90-135V DC at up to about 12mA (<1.7W). So I chose a 5W PCB-mounting mains transformer which I used 'backwards', with the 230V primary used as the secondary output winding.

I determined that I would need a transformer with either 6V+6V or 9V+9V secondaries (acting as the primary here, configured as a single centre-tapped 12V or 18V winding).

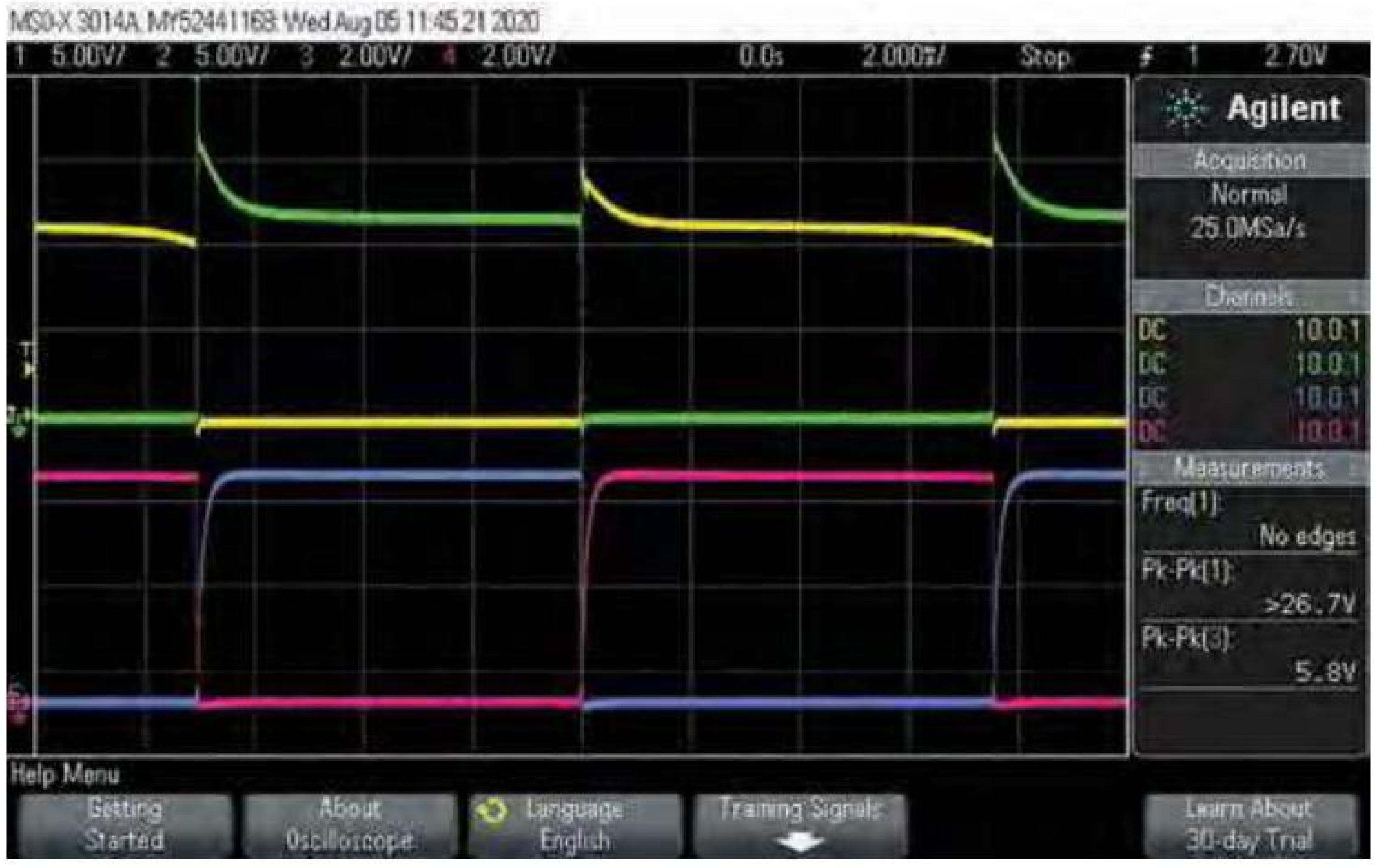
Note that you can't just determine the transformer turns ratio by dividing the secondary voltage into the primary voltage.

Consider the 230V to 6V + 6V transformer; the 6V AC output voltages are determined for a resistive load at full power. With 230V AC on the primary, the 6V windings' open-circuit voltages measure 8.4V AC each. So the actual turns ratio is 230V ÷ 8.4V = 27.5.

Therefore, 8.4V AC is the nominal input voltage when the low-voltage winding is used as the input; but if only 90V output is required, it can be somewhat lower. The small transformer's primary winding DC resistance is around 800Ω, and the low-voltage secondaries measure around 2.5Ω each (or 5.6Ω each for the 9+9V version). This also needs to be considered, as does the high leakage inductance.


MSO-X 3014A, MY52441168: Mon Aug 03 17:13:23 2020
1 2.00V/ 2 2.00V/ 3 2.00V/ 4 2.00V/
0.0s 2.000ms/ Stop 1 2.70V
Agilent
Acquisition
Normal
10.0MSa/s
Channels
DC 10.0:1
DC 10.0:1
DC 10.0:1
DC 10.0:1
Measurements
Freq(1):
68.568Hz
Pk-Pk(1):
5.5V
Pk-Pk(3):
5.8V
Measurement Menu
Source
Type
Pk-Pk
Add
Measurement
Settings
Clear Meas
Statistics

Scope1: scope grab of the oscillator operation, with VR1 and VR2 at their midpoints. The yellow and green traces are the waveforms at the collectors of Q3 and Q4, while the blue and mauve traces are the gate voltages of MOSFETs Q1 and Q2. The duty cycle is not quite 50%, hence the need for adjustability. (Note: the MOSFET switch-on is gradual but switch-off is fast.)


MSO-X 3014A, MY52441168: Wed Aug 05 11:45:21 2020
1 5.00V/ 2 5.00V/ 3 2.00V/ 4 2.00V/
0.0s 2.000ms/ Stop 1 2.70V
Agilent
Acquisition
Normal
25.0MSa/s
Channels
DC 10.0:1
DC 10.0:1
DC 10.0:1
DC 10.0:1
Measurements
Freq(1):
No edges
Pk-Pk(1):
>26.7V
Pk-Pk(3):
5.8V
Help Menu
Getting
Started
About
Oscilloscope
Language
English
Training Signals
Learn About
30-day Trial

Scope2: here the blue and mauve traces are still the gate voltages of Q1 and Q2 while the yellow and green traces are their drain voltages (ie, the push-pull drive to transformer T1). The MOSFETs operate as inverters with significant inductive spikes at switch off; high enough to cause ZD5 and ZD6 to conduct

The relatively high secondary winding resistance (which is the primary in this application) means that the driving MOSFETs don't need any current limiting at switch-on. The peak current is limited by the transformer itself.

Respecting the current ratings for the various windings, an output of up to about 2W is possible; more than enough for this application. The best operating frequency is often above the 50/60Hz recommended for the transformers. The final design provides some frequency adjustment, to let you set the optimal operating point.

The B+ supply normally needs to be galvanically isolated from the filament supply as back-bias is often employed. Because of this, and the fact that the B+ current remains constant, a simple series resistor and zener diode is used to regulate the B+ output. Remember that the 800Ω transformer winding can be used to dissipate some energy.

Caution

Depending on how you configure it, this supply could generate voltages above 60V DC, which is considered the limit of safe 'extra-low voltage' operation. While 100V or so may not seem very high compared to mains voltages, it's certainly high enough to give you a serious shock should you come in contact with the high-tension (HT) side of the circuit.

So you must work in such a way that you can't come in contact with the *Supply* or the HT circuitry it is powering while power is applied. When probing or adjusting the *Supply*, always use tools with sufficiently high voltage ratings. Once it has been set up, it must be housed in such a way that users can't come in contact with any of the HT circuitry, and all wiring should be properly insulated.

If you are already working on valve sets, chances are you will already understand the danger and have safe practices. If you are a novice, seek assistance from a more experienced technician before building or working on this *Supply*.

Circuit description

While the circuit and board are designed to operate from one or two batteries, it's far better to have two batteries: a lower-voltage battery for the A supply and a higher-voltage battery for the B-supply. This improves efficiency and reduces heat dissipation.

My recommendation is that the higher-voltage battery should consist of two Li-ion, LiPo or $LiFePO_4$ cells in series, giving a nominal voltage of around 7.4V (or 6.6V for $LiFePO_4$). You could use two sets of parallel cells if you wanted to – ie, a 2S2P configuration, although that isn't really necessary.

The lower-voltage battery can be one of the same cells, or better, two in parallel. This will then have a nominal voltage of 3.7V or 3.3V, depending on the chemistry.

Assuming that two batteries are used, the higher-voltage battery is connected to CON1 and the lower-voltage battery to CON2 (see Fig.1 above).

Both connections have reverse-polarity protection in the form of series 1A PTC thermistors and reverse-connected 3A diodes, D1 and D2.

Should either battery be connected with the wrong polarity, the associated diode will conduct and cause the PTC to go high-resistance. The radio would then not work, and presumably, this would lead you to discover and correct the problem before the battery discharged. Those PTCs also provide a measure of over-current protection, should something go wrong on the power supply board or in the radio.

The B IN + supply from CON1 then goes through P-channel MOSFET switch Q5 and runs the high-voltage B-supply generator, while the A IN + supply from CON2 goes through a similar MOSFET switch (Q6) and onto the A-supply generator. These MOSFETs provide the low-battery cut-out protection, which will be described later.

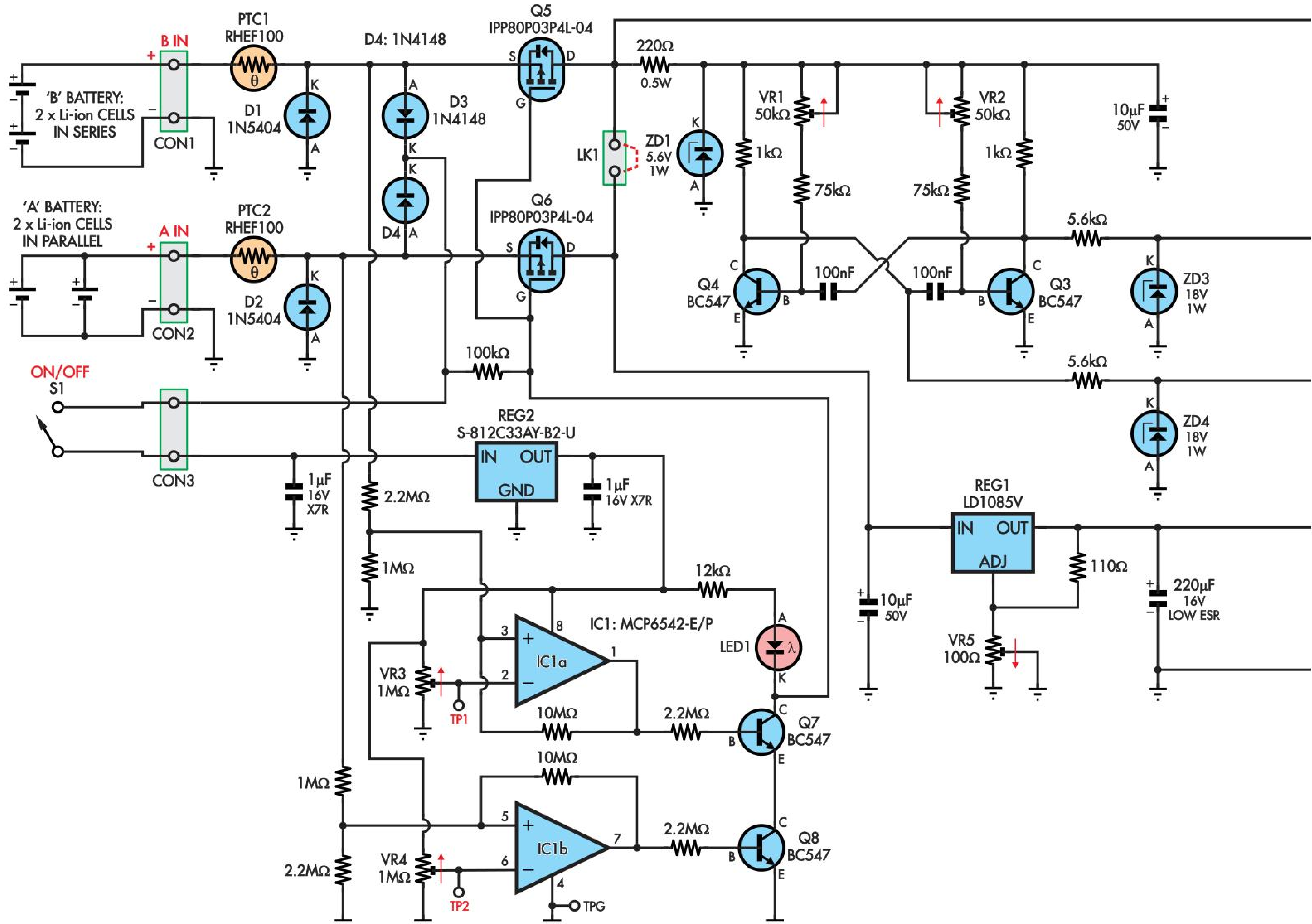
If a single battery is used, CON2, PTC2, D2, D4 and Q6 are left off the board, and a wire link is soldered across LK1. The B IN + supply then goes through switch Q5 and onto both the A-supply and B-supply generators. More on this possibility later.

High-voltage generator

As well as the description below, the operation of this part of the circuit is depicted in oscilloscope grabs Scope1-Scope5 overleaf. With MOSFET Q5 on, current flows through the 220Ω resistor to charge the 10µF bypass capacitor for

Features and specifications

- Runs from two or four Li-ion, LiPo or $LiFePO_4$ batteries (typically two series cells for the HT generator and two parallel cells for LT)
- HT output (B): 24-135V DC at up to 2W
- LT output (A): 1.2-2.5V at up to 3A (with a heatsink)
- Low-battery cut-out voltages: 0-10V (B), 0-4.5V (A)
- Quiescent current when off: around 10µA (B) and 2µA (A)
- HT operating current (B): around 300mA @ 6.2V for 135V HT
- LT operating current (A): 5-10mA plus what the radio draws
- Other features: low EMI, indicator LED, provision for low-current SPST on/off switch, adjustable transformer drive frequency and duty cycle.


PTC1
RHEF100
B IN
+
–
'B' BATTERY:
2 x Li-ion CELLS
IN SERIES
CON1
D1
1N5404
K
A
D4: 1N4148
D3
1N4148
D4
Q5
IPP80P03P4L-04
S
D
G
220Ω
0.5W
LK1
ZD1
5.6V
1W
VR1
50kΩ
1kΩ
75kΩ
VR2
50kΩ
1kΩ
75kΩ
10µF
50V
'A' BATTERY:
2 x Li-ion CELLS
IN PARALLEL
A IN
PTC2
RHEF100
CON2
D2
1N5404
Q6
IPP80P03P4L-04
Q4
BC547
C
B
E
100nF
100nF
Q3
BC547
5.6kΩ
ZD3
18V
1W
100kΩ
5.6kΩ
ZD4
18V
1W
ON/OFF
S1
CON3
REG2
S-812C33AY-B2-U
IN
OUT
GND
1µF
16V
X7R
2.2MΩ
1µF
16V X7R
REG1
LD1085V
IN
OUT
ADJ
110Ω
10µF
50V
220µF
16V
LOW ESR
1MΩ
12kΩ
IC1: MCP6542-E/P
IC1a
LED1
λ
VR3
1MΩ
TP1
10MΩ
2.2MΩ
Q7
BC547
VR5
100Ω
10MΩ
1MΩ
IC1b
2.2MΩ
Q8
BC547
VR4
1MΩ
TP2
2.2MΩ
TPG
3
2
8
1
5
6
7
4

Battery Vintage Radio Power Supply

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the oscillator. The voltage across that capacitor, and thus the oscillator supply, is clamped to around 5.6V by zener diode ZD1 for consistent operation.

NPN transistors Q3 and Q4 form a basic oscillator, with trimpots VR1 and VR2 providing a small amount of both duty cycle and frequency adjustment. This allows you to tune the oscillator to get a 50% duty cycle for the most efficient driving of transformer T1, and to adjust the frequency to tweak the power delivery to suit your radio.

The oscillation frequency is determined by the time constant of the resistances and capacitors connected to the bases of transistors Q3 and Q4.

With VR1 and VR2 centred, R = 100kΩ and C = 100nF, so the approximate frequency is $1/(1.38RC)$ = 72.5Hz. Setting VR1 and VR2 at the extremes, it can be varied from about 54Hz up to 96.5Hz.

The duty cycle is adjusted by varying the resistance of one trimpot slightly compared to the other.

Drive for the gates of MOSFETs Q1 and Q2 comes from the collectors of Q3 and Q4 via 5.6kΩ current-limiting resistors. These form RC low-pass filters with the MOSFET gate capacitances, and their values may be increased if switching noise is a problem.

The 18V zeners protect the MOSFETs from an excessive gate-source voltage which might be caused by back-EMF from the transformer coupling through the MOSFET parasitic capacitances. In practice, they rarely conduct.

Q1 and Q2 drive the 'primary' of transformer T1 in push-pull fashion. The 9+9V windings are intended to be the transformer's secondaries when it is operated from the mains, but here we are using it in the opposite manner. T1's centre tap connects to the battery supply before the 220Ω resistor, so that the transformer has a low source impedance. It draws around 0.5A when delivering more than 2W at 100V.

Note that Q1 and Q2 must be logic-level MOSFETs as they will typically receive a maximum gate-source voltage of around 5V.

The output of T1 is rectified by BR1 to charge the first 100µF capacitor. The second 100µF capacitor forms a low-pass filter with the 100Ω resistor to reduce ripple, while zener diode ZD2 limits the voltage applied to the radio until its HT current draw comes up to normal. After that, it's limited by the transformer and 100Ω series resistor.

Note that high-voltage zener diodes have quite high zener impedances, so for example, if ZD2 is a 75V diode, the B+ OUT voltage could easily exceed 85V at light loads. This is unlikely to damage any radio, and it will drop to a more normal level as the radio draws more current. ZD2 is just there to prevent wildly high HT voltages from being applied.

Filament supply

The filament supply is based around adjustable linear regulator REG1. This is similar to the LM317 but can deliver more current; over 3A, rather than 1.5A. The LD1085 also has a lower dropout voltage than the LM317 at similar currents, although that isn't important here.

The A OUT voltage is adjusted using trimpot VR5, which forms a divider with the 110Ω resistor between the OUT and ADJ terminals. As there is a fixed voltage between OUT and ADJ, and a fixed resistance, that means that the current through VR5 is essentially constant. So

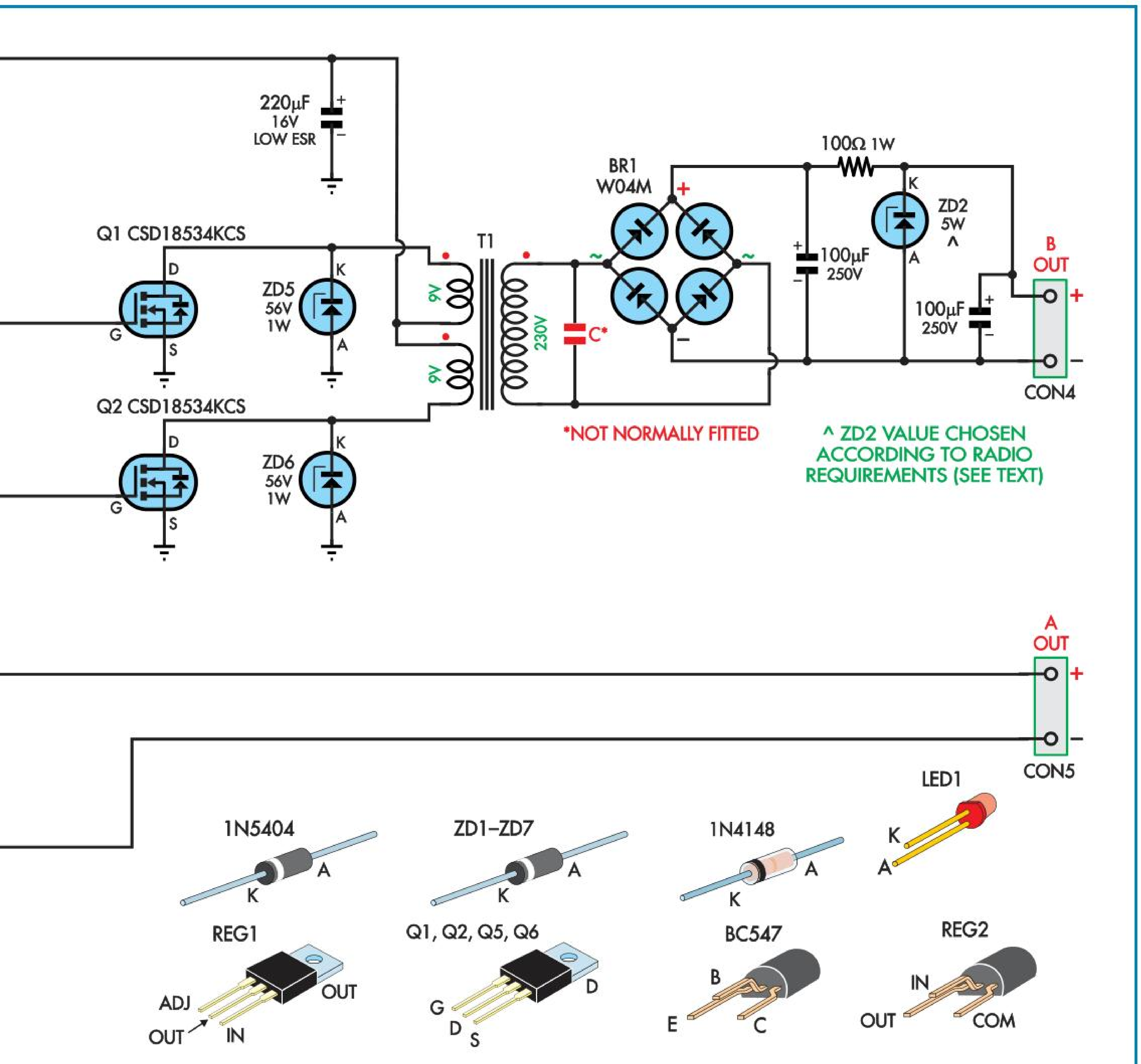


Fig.1: the left-hand section of the *Battery Vintage Radio Power Supply* circuit provides input protection and the low-battery cut-out function, while the middle section is the HT drive oscillator and LT regulator. The oscillator drives the step-up section at upper right, with T1 providing high voltage AC that's rectified by BR1 and filtered by two electrolytic capacitors and a resistor to give relatively smooth HT DC.

by varying its resistance, we vary the voltage between ADJ and GND, and thus set a fixed output voltage.

A typical 5-valve portable radio (eg, the Aristocrat Tecnico 859) with a valve compliment of 1T4, 1R5, 1T4, 1S5 and 3S4 will require 300mA at 1.4V for the filaments. So with a 3.7V battery, the regulator will dissipate (3.7 – 1.4) × 0.3 = 0.69W (690mW) so little heatsinking is required for REG1.

The heatsinking of REG1 can be adjusted as required; some heatsinking was required for my Velco radio.

You could use a flag heatsink, as we did on our prototype, or bolt the regulator to a piece of metal, such as the chassis.

Note than some battery radios had the filaments connected in series. Those radios will need a filament supply of something like 7.5V @ 50mA. This circuit would be suitable for such radios with a few tweaks.

For example, the 110Ω resistor would have to increase to say 620Ω to give REG1 sufficient adjustment range, and the B+ battery would probably need to be three Li-ion, LiPo or $LiFePO_4$ cells in series to give REG1 a sufficiently high input for regulation, even when the battery is almost flat.

The resistors connected to pin 5 of IC1b would also need to change from 1MΩ/2.2MΩ to something like 3.3MΩ/1MΩ so that the low-battery cut-out adjustment range would suit that battery.

Low-battery protection

MOSFET switches Q5 (and Q6, if fitted) are used to provide low-battery protection. If either battery's voltage drops below a critical level, Q5 and Q6 switch off, so the power supply and radio shut down. In this state, the circuit only draws about 10µA from the B-battery and about 2µA from the A-battery.

Presumably, you would notice the radio has switched off and either recharge them or swap them for fresh cells. But if for some reason you forget and leave the radio switched on, it would be several months before this minimal current drain could damage the cells. That's why this circuit was designed with a low quiescent current in mind.

When power switch S1 is closed, current can flow from whichever battery has a higher voltage, through small signal diodes D3 and D4 and then switch S1, into the input of REG2. This is an ultra-low-quiescent-current, low-dropout 3.3V linear regulator. It powers micropower dual comparator IC1 and also serves as a voltage reference.

A fraction of this 3.3V reference is fed to the two inverting inputs of the comparators, at pin 2 and 6 of IC1. The fraction that is applied to those pins depends on the rotation of trimpots VR3 and VR4. These set the low-battery cut-out voltages, and they can vary the voltage at those inputs over the full range of 0-3.3V.

The actual battery voltages are applied to the non-inverting inputs, pins 3 and 5, after passing through fixed resistive dividers. While these two dividers use the same resistor values, they are in different orders. So around 1/3 of the B-battery voltage is applied to pin 3 of IC1a, while about 2/3 of the A-battery voltage is applied to pin 5 of IC1b.

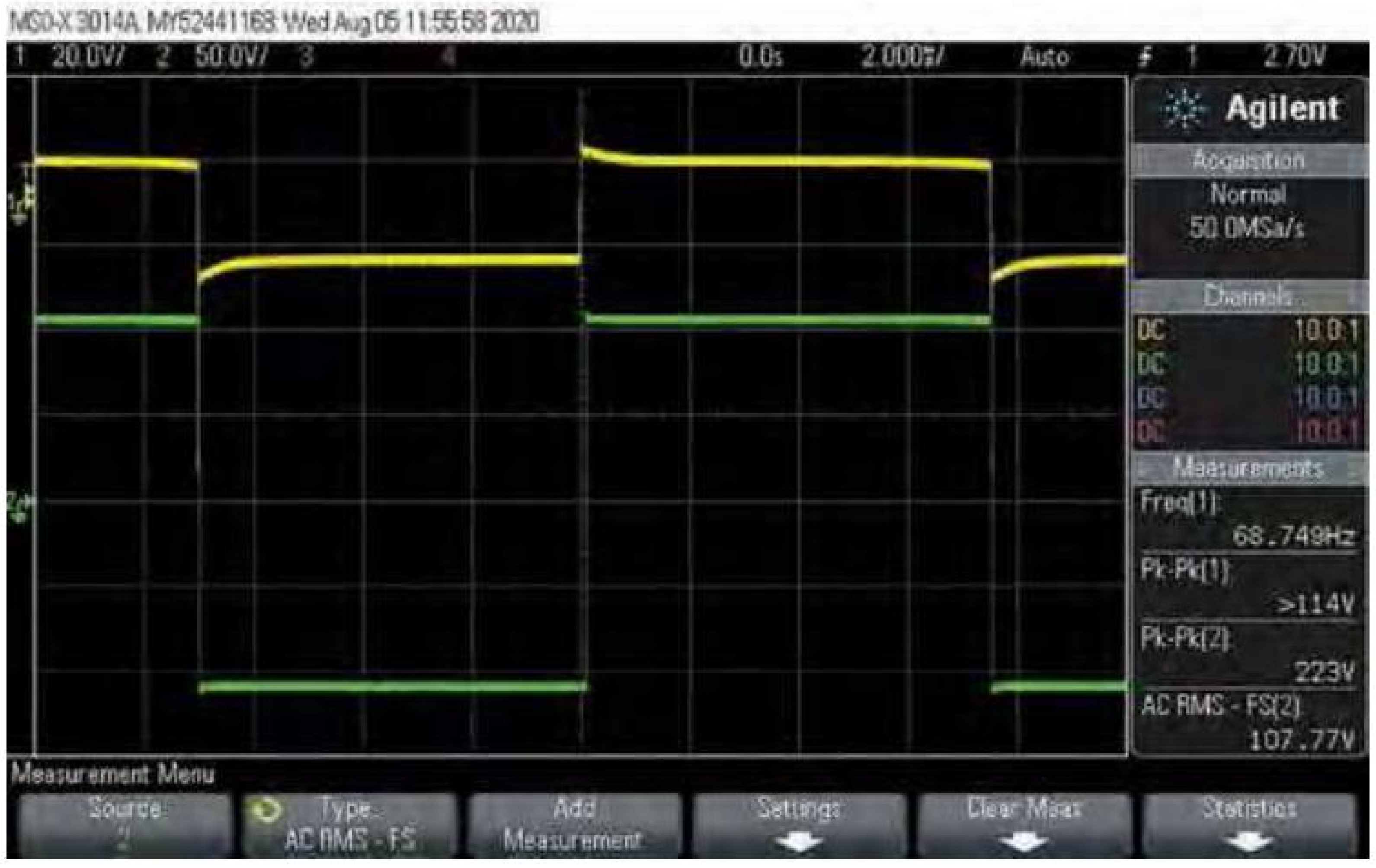
In combination with the nominally 3.3V reference and trimpots VR3 and VR4, that means that you can set the switch-on voltage thresholds to anywhere from 0-10V for the B-battery, and 0-4.5V for the A-battery. Those ranges are slightly wider than necessary, to allow for variations in the exact regulator output voltage between samples.

Hysteresis is provided by 10MΩ feedback resistors between the comparator outputs and non-inverting inputs. This has been arranged so that the hysteresis is a fixed percentage of the voltage.

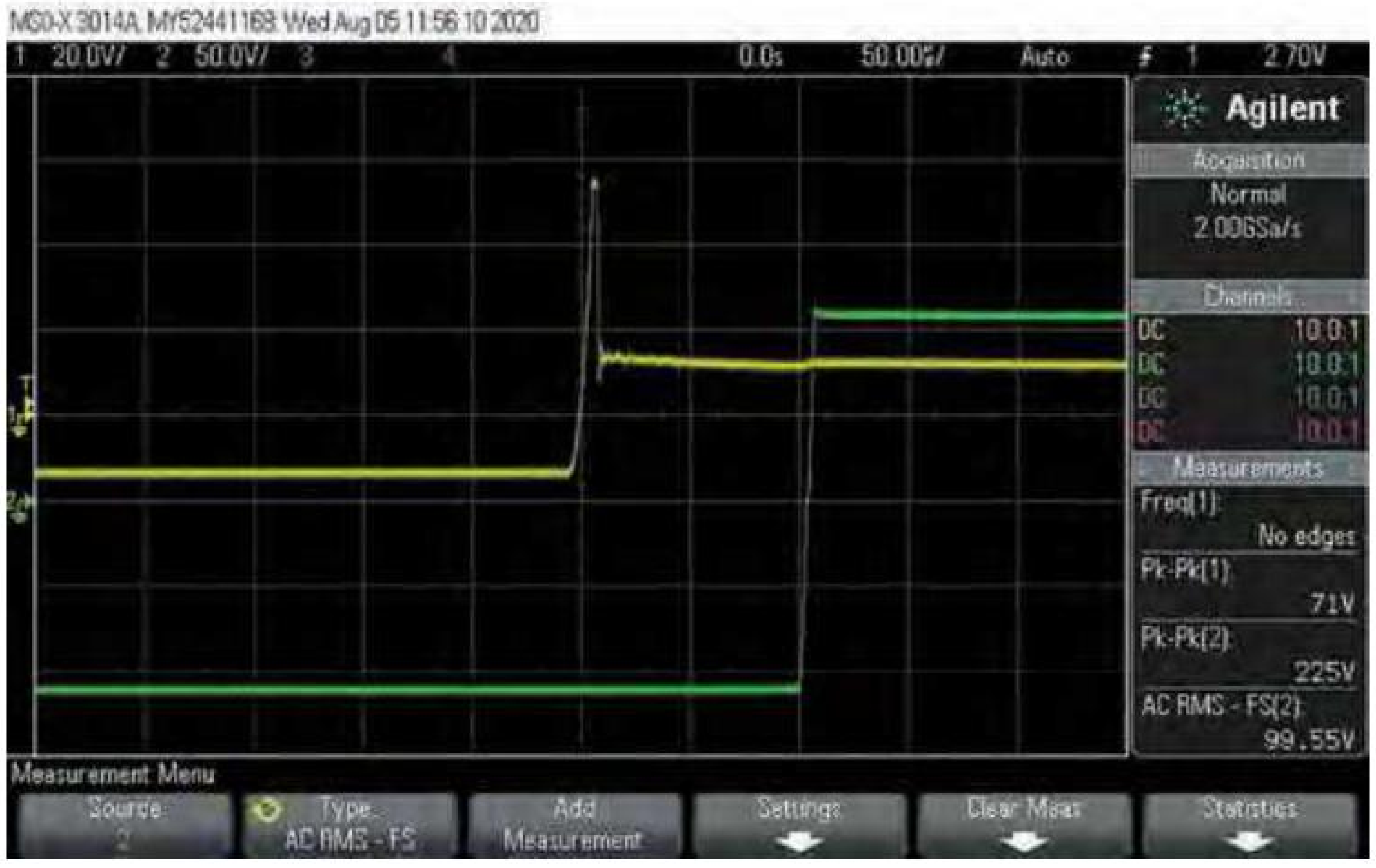
The source impedance for the non-inverting inputs is 687.5kΩ in both cases (1MΩ||2.2MΩ), and this forms a divider with the 10MΩ feedback resistor. It gives a hysteresis percentage of 687.5kΩ ÷ 10MΩ = 6.875%

So for low-battery cut-out voltages of 3.3V and 6.6V for the A and B batteries, that would give you switch-on voltages 6.875% higher, or 3.525V and 7.05V respectively. The resulting hysteresis voltages are around 0.23V for the A-battery and 0.45V for the B-battery. When both batteries are above their switch-on voltages, output pins 1 and 7 of IC1 are high, at 3.3V. Therefore, the base-emitter junctions of NPN transistors Q7 and Q8 are forward-biased and so both conduct, pulling the gates of MOSFETs Q5 and/or Q6 low and lighting LED1. If either battery falls below its switch-off voltage, the corresponding transistor switches off and thus Q5 and Q6 switch off.

High base resistors for Q7 and Q8 (2.2MΩ) are used because if one battery voltage is low but the other is high, current will still flow from the corresponding comparator output and this will increase the current drawn from the higher voltage battery (usually the B-battery).


MSO-X 3014A, MY52441168: Wed Aug 05 11:55:58 2020
1 20.0V/ 2 50.0V/ 3 4
0.0s 2.000ms/ Auto
1 2.70V
Agilent
Acquisition
Normal
50.0MSa/s
Channels
DC 10.0:1
DC 10.0:1
DC 10.0:1
DC 10.0:1
Measurements
Freq(1):
68.749Hz
Pk-Pk(1):
>114V
Pk-Pk(2):
223V
AC RMS - FS(2):
107.77V
Measurement Menu
Source 2
Type AC RMS - FS
Add Measurement
Settings
Clear Meas
Statistics

Scope3: the yellow trace is the drive voltage across T1's primary (ignoring the centre tap), while the green trace is the voltage across the secondary. Note the different scales: 20V/div for the primary and 50V/div for the secondary. The secondary shows little overshoot and no ringing.


MSO-X 3014A, MY52441168: Wed Aug 05 11:56:10 2020
1 20.0V/ 2 50.0V/ 3 4
0.0s 50.00µs/ Auto
1 2.70V
Agilent
Acquisition
Normal
2.00GSa/s
Channels
DC 10.0:1
DC 10.0:1
DC 10.0:1
DC 10.0:1
Measurements
Freq(1):
No edges
Pk-Pk(1):
71V
Pk-Pk(2):
225V
AC RMS - FS(2):
99.55V
Measurement Menu
Source 2
Type AC RMS - FS
Add Measurement
Settings
Clear Meas
Statistics

Scope4: a close-up of the edge of the waveform in Scope3. Here you can clearly see the primary overshoot is limited to around 60V by ZD5 and ZD6, which each conduct for around 3-5µs per cycle, protecting Q1 and Q2 from excessive drain voltages (although they are avalanche rated, so would likely survive). Note the 100µs delay between the leading edges of the primary and secondary waveforms.

The 2.2MΩ base resistors are the highest practical values to minimise this, and determine the minimum value for an LED's current-limiting resistor as 12kΩ. That means that LED1 has to be a high-brightness type.

On/off switch

If you don't need a power switch on the supply, you can simply place a shorting block on CON3. We have provided CON3 as a convenient way to switch power on and off, and you only need an SPST switch that hardly has to handle any current.

But with S1 off, there will still be a small quiescent current drawn from the two batteries due to the resistive dividers which remain connected. This is around 1.5µA from the A-battery and 3µA from the B-battery. That should mean the batteries last for around a year with the radio switched off.

If you need to reduce the battery drain when off, you will instead need to use a DPST or DPDT switch to cut the battery connections to CON1 and CON2. That switch will need to handle the full load current of at least 1A for each battery. Note that the batteries may still suffer from a small amount of self-discharge, so it's still a good idea to check and charge them every six months or so.

Selecting ZD2

Four 5W zener diode options are given in the parts list, to suit different radio requirements. Common radio B-battery voltages are 22.5V, 45V, 67.5V and 90V. Choose the diode type with a voltage rating just slightly higher than your B-battery voltage. Our suggestions are 24V, 47V, 68V and 91V respectively. For a 135V HT, you can use a 130V or 150V zener.

Once the radio has warmed up, you can adjust the transformer drive frequency to get a voltage close to the rated B-battery voltage. The 5W zener diode (ZD2) is mainly included to limit the supply voltage before the valve filaments reach full emission.

Note that it isn't uncommon for the voltage to still rise by 5-10V or more above nominal initially, due to the relatively high zener impedance of these parts (it's higher for higher voltage zeners). This usually should not cause any problems for most radios, given that it should still be within about 10-15% of the nominal voltage and won't usually happen continuously unless there is a radio fault.

Choosing a transformer

The 9V+9V version (Myrra 44236) should suit most constructors. With a 9V DC input, it will deliver around 100V into a 5kΩ load (20mA), or around 100V into a 10kΩ load (10mA) at 7.5V DC.

It's only if you need more current than this, especially at the upper end of the voltage range (approaching 135V) that you might need to substitute the 6V+6V transformer, which will give you a bit more HT power.

As the battery discharged, I did find that the HT dropped a bit with my test sets during use with the 9V+9V transformer. However, I didn't notice any variation in performance as a result of this.

PCB design

All of the HT tracks and components on the PCB have been spaced apart by 2.54mm, which is enough gap to suit mains voltages (350V+ DC peak). This isn't strictly necessary, but it was possible without increasing the board size, so I did it. There is one component (ZD2) that carries HT that's quite close to one edge of the board, so avoid putting that edge right up against anything conductive.

You could add some neutral-cure silicone sealant around its leads and the solder joints on the underside if you wanted extra insulation. But note that this part can get quite hot at times. For that reason, we've also increased the amount of copper on the PCB connecting to its leads on both sides; this helps to draw some extra heat away (although its 5W rating is already pretty generous).

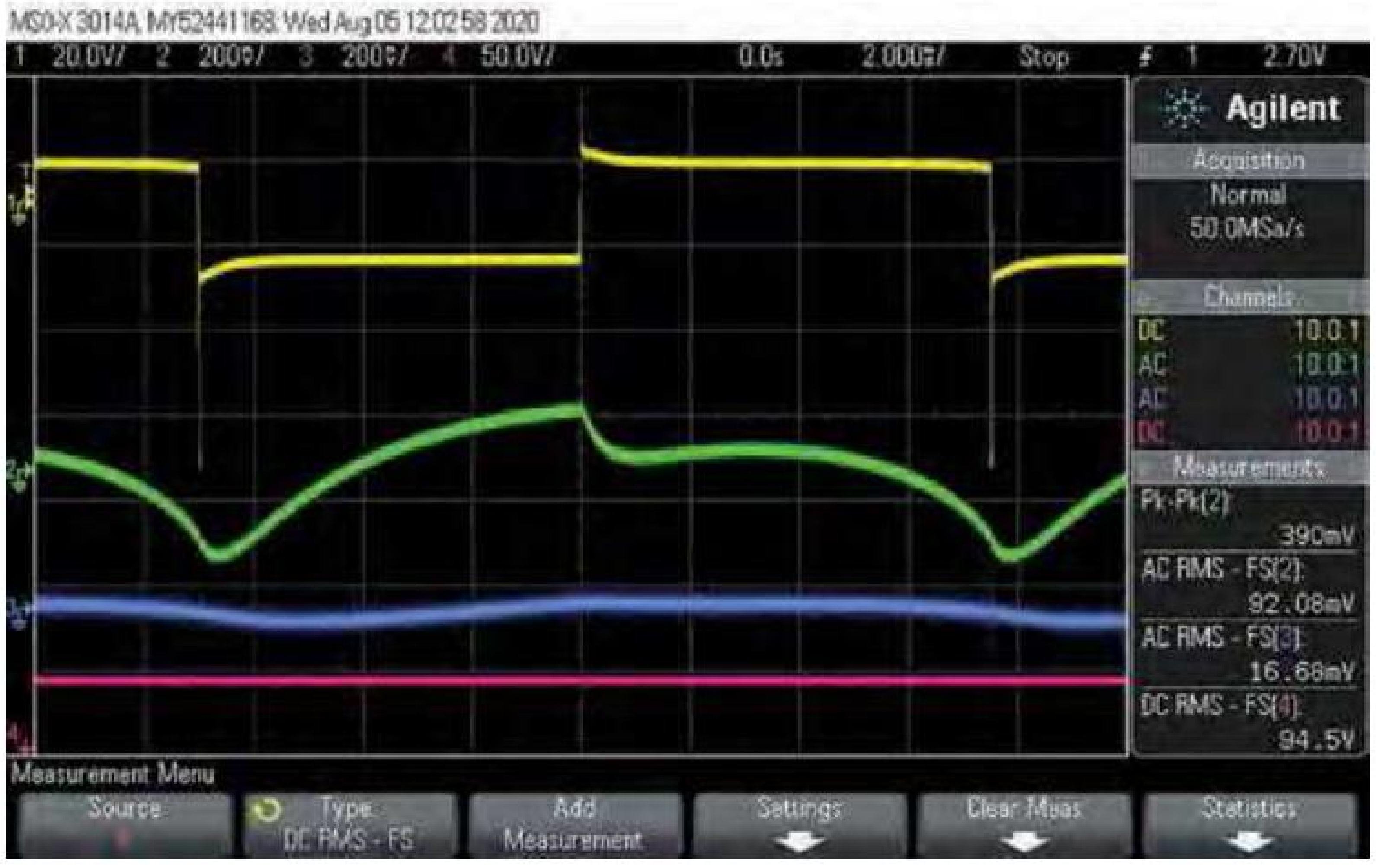
Construction

The *Battery Vintage Radio Power Supply*, available from the PE PCB Service, is built on a double-sided PCB coded 11111201 and measures 125 × 54.5mm. It has been made as compact as possible, within reason, so you can fit it and the Li-ion cells in the space that would have been occupied by the original batteries.

Refer now to Fig.2, the PCB overlay diagram, which shows where all the parts go.

My original design used mostly SMD components, with many of them mounted under transformer T1, and therefore managed to be a bit more compact than this one. But I think that a lot of Vintage enthusiasts would find it fiddly to build, hence this all-through-hole version, which still manages to be fairly compact.

Start by fitting all the small resistors – leave the 1W resistor off, for now. While you can determine the value of a resistor by reading its colour bands, it's best to use a DMM set to measure ohms to verify this, as some colours can look like other colours under certain types of light.



Scope5: the yellow trace is again the transformer primary waveform while the green trace is the voltage across the first 100µF capacitor, and the blue waveform is the voltage across the HT output, with a 20mA load (94.5V into 4.7kΩ or 1.9W). You can see that the ripple before the RC filter is very modest at 92mV RMS, and it's even less after; just 16.7mV RMS.

If you are using a single battery to power the *Supply*, bend one of the resistor lead off-cuts to form link LK1 and solder it to the board in place of the header shown in Fig.2; otherwise, leave LK1 off. As you read the following instructions, keep in mind that you will not be fitting the middle terminal block (CON2), PTC2, diodes D2 or D4, or MOSFET Q6.

Mount the smallest diodes, D3 and D4, then all the 1W zener diodes, ZD1 and ZD3-ZD6. All of these must be oriented with their cathode stripes facing as shown in Fig.2.

At this point, it's a good idea to fit comparator IC1. Make sure its pin 1 notch and dot go towards the top of the board, as shown in Fig.2. I don't recommend using a socket for reliability reasons, although you could if you wanted to.

With that in place, mount the larger diodes D1 and D2, again watching the cathode stripe orientation. Then fit bridge rectifier BR1, ensuring that its longer positive lead goes to the pad marked '+' (its other leads should also have their functions printed on the top of the package). Push it all the way down before soldering and trimming its leads.

Now fit switch header CON3. You can use a regular or polarised header, or just solder a couple of wires to the PCB. If you want the *Supply* to always be on, you can either place a shorting block on CON3 or solder a small wire link in its place.

The next step is to fit small signal diodes Q3, Q4, Q7 and Q8. They are all the same type; ensure their flat faces face as shown in the overlay diagram, and bend their leads out gently to fit the pad patterns.

Follow with small regulator REG2, which is in a similar package to those transistors, then install the four ceramic and MKT capacitors where shown.

Now mount the five trimpots, making sure that you don't get the three different types mixed up. VR1 and VR2 are 50kΩ (and may be marked 503), VR3 and VR4 are 1MΩ (may be marked 105) while VR5 is 100Ω (may be marked 100).

The next step is to fit the smaller electrolytic capacitors, ensuring that their longer leads go to the pads marked with a '+' symbol on the PCB (the striped side of each can indicates the negative lead). Leave the high-voltage capacitors for later.

Follow with the two PTCs, which are not polarised, and then the four terminal blocks. Make sure their wire entry holes face towards the outside of the module, and note that the three side-by-side blocks are spaced apart and so should not be dovetailed; mount them individually.

Now fit the five TO-220 devices, which all mount vertically. Make sure you don't get them mixed up (see Fig.2 and Fig.1 or the parts list), and also ensure that their metal tabs are oriented as shown. You may wish to bend the leads of REG1 slightly before fitting it so that its tab is flush with or beyond the edge of the PCB, to make it easier to mount a heatsink later.

Parts list – Battery Vintage Radio Power Supply

1 double-sided PCB coded 11111201, 125 x 54.5mm,
  available from the *PE PCB Service*
1 Myrra 44236 9+9V PCB-mount transformer (T1)
  [element14 1214600, RS 173-9939] ***or***
1 Myrra 44235 6+6V PCB-mount transformer (T1)
  [element14 1214599, RS 173-9923] (see text)
2 RHEF100 or RHEF100-2 1A PTC/polyswitches (PTC1 and 2)
  [element14 3296327, RS 657-1772]
4 2-way terminal blocks, 5.08mm pitch (CON1,2,4,5)
1 2-pin header or polarised header with jumper shunt (CON3)
1 SPST panel-mount switch (S1; optional)
4 tapped spacers (for mounting the PCB) *to match screws below*
8 M3 x 6mm panhead machine screws (for mounting the PCB)
1 flag heatsink with TO-220 insulating washer and bush
  (for REG1; optional)
1 M3 x 10mm panhead machine screw, nut and two washers
  (for mounting the flag heatsink)

Semiconductors

1 MCP6542-E/P dual micropower comparator, DIP-8 (IC1)
  [element14, RS, Digi-Key, Mouser]
1 LD1085V 3A adjustable regulator, TO-220 (REG1)
  [element14, RS, Digi-Key, Mouser]
1 S-812C33AY-B2-U micropower low-dropout regulator,
  TO-92 (REG2) [Digi-Key, Mouser]
2 CSD18534KCS N-channel logic-level MOSFETs, TO-220
  (Q1,Q2) [element14, Digi-Key, Mouser]
4 BC547 100mA NPN transistors, TO-92 (Q3,Q4,Q7,Q8)
2 IPP80P03P4L04 P-channel logic-level MOSFETs,
  TO-220 (Q5,Q6) [element14, RS, Digi-Key, Mouser]
1 high-brightness LED (LED1)
1 5.6V 1W zener diode (ZD1)
1 24V 5W zener diode (1N5359B) (ZD2) [^] ***or*** *[^ element14,*
1 47V 5W zener diode (1N5368B) (ZD2) [^] ***or*** *Digi-Key,*
1 68V 5W zener diode (1N5373B) (ZD2) [^] ***or*** *Mouser]*
1 91V 5W zener diode (1N5377B) (ZD2) [^] ***or***
1 130V 5W zener diode (1N5381B) (ZD2) [^] (see text)
2 18V 1W zener diodes (ZD3,ZD4)
2 56V 1W zener diodes (1N4758) (ZD5,ZD6) [^]
1 W04M 1.5A bridge rectifier (BR1)
2 1N5404 400V 3A diodes (D1,D2)
2 1N4148 small signal diodes (D3,D4)

Capacitors

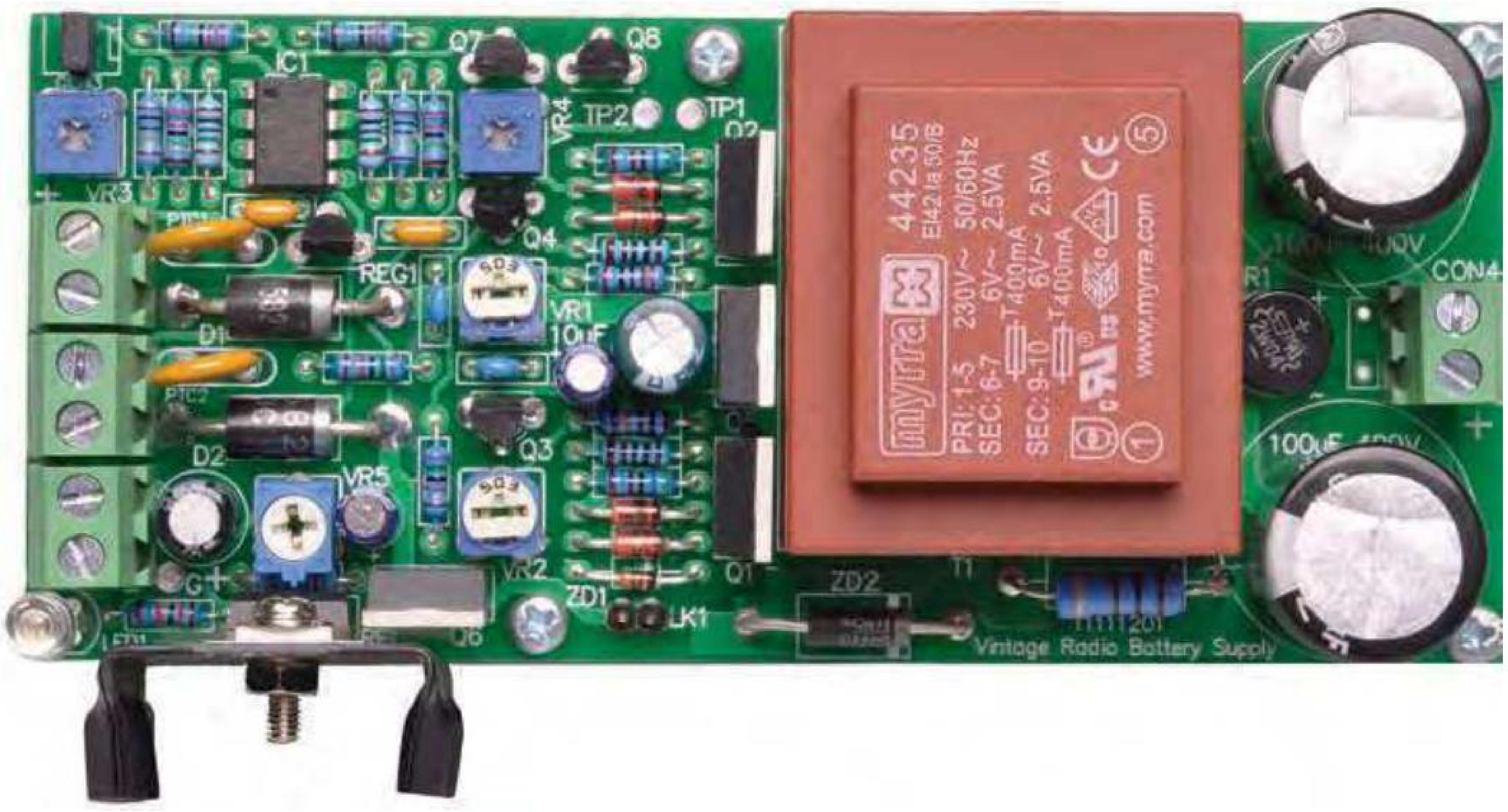
2 220µF 16V low-ESR electrolytic
2 100µF 250V/400V electrolytic [eg, Panasonic EEUED2E101S]
2 10µF 50V electrolytic
2 1µF 50V multi-layer ceramic
2 100nF 63V MKT

Resistors (all 1% metal film except where indicated)

2 10MΩ 4 2.2MΩ 2 1MΩ 1 100kΩ
2 75kΩ 1 12kΩ 2 5.6kΩ 2 1kΩ
1 220Ω 1 110Ω 1 100Ω 1W 5%
2 50kΩ mini horizontal trimpots (VR1,VR2)
2 1MΩ mini horizontal trimpots (VR3,VR4)
  [eg, element14 108244]
1 100Ω mini horizontal trimpots (VR5)
  [eg, element14 2859725]

Follow by mounting the two remaining capacitors. There are pads for a 7.5mm-pitch standard radial capacitor or a

This photo of the assembled PCB is, like the diagram below, at 1:1 scale. Not shown here are the battery holders because these will depend on the batteries you use and the way they are set up. You need 7.4V on CON1 – easily achieved with a dual '18650' battery holder (two cells in series). For the 3.7V required for CON1, we used a pair of single battery holders connected in parallel.



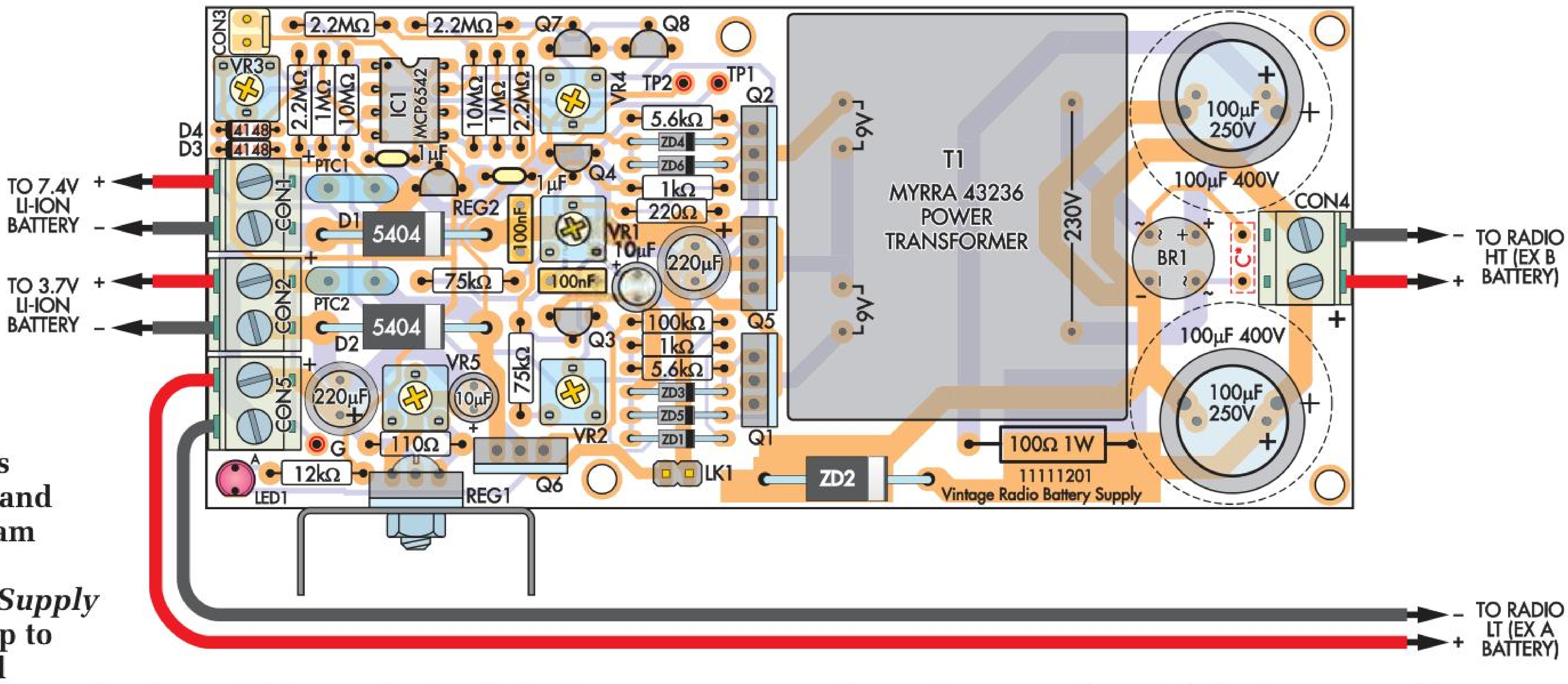

CON3
2.2MΩ
2.2MΩ
Q7
Q8
VR3
2.2MΩ
1MΩ
10MΩ
IC1 MCP6542
10MΩ
1MΩ
2.2MΩ
VR4
TP2
TP1
Q2
D4 4148
D3 4148
5.6kΩ
ZD4
ZD6
PTC1
1µF
1µF
Q4
1kΩ
220Ω
TO 7.4V LI-ION BATTERY
CON1
D1 5404
REG2
100nF
VR1
10µF
220µF
TO 3.7V LI-ION BATTERY
CON2
PTC2
75kΩ
100nF
D2 5404
Q3
100kΩ
1kΩ
5.6kΩ
Q5
VR5
75kΩ
220µF
10µF
CON5
ZD3
ZD5
ZD1
VR2
Q1
G
110Ω
A
LED1
12kΩ
REG1
Q6
LK1
ZD2
100Ω 1W
11111201
Vintage Radio Battery Supply
T1
MYRRA 43236 POWER TRANSFORMER
9V
9V
230V
100µF 250V
100µF 400V
BR1
C
CON4
100µF 400V
100µF 250V
TO RADIO HT (EX B BATTERY)
TO RADIO LT (EX A BATTERY)

Fig.2: use this PCB overlay and wiring diagram as a guide to building the *Supply* and wire it up to the radio and batteries. Construction is straighforward; simply fit the components as shown here, starting with the lowest profile types and working your way up to the highest profile. Make sure that polarised components like the IC, diodes, MOSFETs, regulators and electrolytic capacitors go in the right way around.

10mm-pitch snap-in capacitor. The former suits the 250V Panasonic capacitor mentioned in the parts list, while the 10mm pads should suit the Altronics Cat R5368 100µF 400V capacitor. You might also be able to get Jaycar Cat RE6156 (100µF 400V) to fit with a bit of lead bending.

Fitting the transformer

The transformer has four leads on one side and two on the other, and these should be an exact fit for the PCB pads. I had to do quite a bit of 'massaging' of the leads to get them to go in as they are such a precise fit. I found that tweezers are a good tool for this, as you can slip them in under the transformer and gently bend and coerce the leads until they all pop into their respective holes.

Make sure the transformer is pushed down all the way onto the board before soldering and trimming its leads.

The transformer will now make a nice steady base as you mount the 1W resistor and 5W zener diode (ZD2). While you could push these all the way down onto the board, it will aid in convective cooling if you space them off the board at least a few millimetres. I raised them by about 8mm above the top of the PCB on my prototype. Remember to choose ZD2 based on your radio's HT voltage.

You can now install LED1. How you do this depends on what your plans are with it. If you don't need an external power-on LED indicator, you can simply push it right down (with its longer lead on the side marked 'A', opposite the flat on the lens) and solder it in place. Or you could bend it over at right-angles, facing away from the module.

If you want it to be externally visible, it would be best to chassis-mount it using a bezel. You could then either solder flying leads from its leads to the PCB pads, or solder a 2-pin header (regular or polarised) onto the PCB and then solder leads to the LED with a plug or plugs at the other end.

If your radio will be drawing more than about 500mA from CON5, especially if there is a big difference between its LT voltage and the battery supply, fit a flag heatsink to REG1. I used an insulating washer and insulation bush mainly to ensure good contact between the heatsink and regulator, but it's also a good idea in case the heatsink could short to a metal case, the chassis or anything else.

You will definitely need to insulate the tab from the case or chassis (using an insulating washer and bush) if you are mounting it directly to the case/chassis for cooling.

That just leaves the four tapped spacers, which you can attach to the provided holes on the board, for mounting the module to your radio case (or wherever you plan to use it).

Testing and adjustment

It's best to test and adjust the *Supply* using a variable DC bench supply; ideally one with current limiting. You'll also need a DMM at the ready, set to a high volts range. The board can generate some hazardous voltages, so make sure that it is in a location where it can't short against anything and where you can probe it without any risk of coming in contact with the board.

Start by centring trimpots VR1 and VR2, setting VR3 and VR4 at maximum and VR5 to its minimum. If you've built the two-battery version, bridge the positive inputs together (you don't need to bridge the negative terminals as they are connected on the PCB). Set your bench supply to around 4V and the current limit to a low value, then switch it off and wire up either input (CON1 or CON2) to the supply.

Switch the supply on and watch LED1. It should not light yet, and the current drawn from the supply should be low (under 1mA). If it's significantly higher than that, you could have a board fault, so switch off and check for short circuits and incorrectly located or oriented components.

If all is well, increase the current limit to around 1A and wind the voltage up to about 8V, then rotate VR3 anti-clockwise until LED1 lights up. The circuit has now powered up, so check the voltage across the CON4 output. It should be slightly higher than the voltage rating of zener diode ZD2. You may notice ZD2 and/or the 100Ω resistor getting warm.

Also check the output voltage at CON5. It should be around 1.2V. Check that you can vary it by adjusting trimpot VR5. You might as well set it to your desired voltage while you're at it.

Now rotate VR3 and VR4 fully anti-clockwise, set the supply voltage to your desired A-battery (Li-ion) cut-out voltage, then rotate VR4 clockwise slowly until LED1 switches off. Then increase the supply voltage to your desired B-battery cut-out voltage; LED1 should switch back on. Rotate VR3 slowly clockwise until the unit switches off. You have now set both battery cut-out thresholds.

To set the ideal operating frequency, you will need to connect your actual radio to the outputs (after powering the supply down). Power it back on and wind the supply voltage back up to your nominal battery voltage (around 7.4V for two Li-ion or LiPo cells in series).

Switch the radio on and after it has warmed up, make sure it is working normally. Then adjust VR1 and VR2 in lock-step (eg, making small changes in one, then the other) while monitoring the HT voltage. Adjust until you achieve the specified voltage, or as close to it as you can get. Once you have done that, if you have a scope, you can adjust for 50% duty cycle in the transformer drive.

Power down the circuit and connect the scope up to the ends of the 5.6kΩ resistors closest to MOSFETs Q1 and Q2 and connect the scope's ground to circuit ground (eg, the anode of D1 or D2).

Power it back on and adjust VR1 and VR2 by small amounts in opposite directions until you achieve pulse widths on both channels that measure the same.

Minimising EMI radiation

While this circuit has low EMI, component variations could mean that yours radiates enough to affect radio reception. If so, try increasing the values of the two 5.6kΩ resistors. These slow the switch-off of MOSFETs Q1 and Q2, reducing the spikes at the transformer primaries. These should ideally be below the 56V conduction threshold of zener diodes ZD3 and ZD4.

Test the supply with your radio tuned off-station. If you hear hash, try increasing the 5.6kΩ resistors to 15-22kΩ or possibly higher.

If you have a scope, check the waveforms at the cathodes of ZD5 and ZD6 to see that the spikes have been reduced or just test it again with the radio.

You may need to re-tweak the frequency/HT voltage after doing that. You should eventually arrive at settings for VR1 and VR2 that satisfy both conditions.

It's then just a matter of mounting the *Battery Vintage Radio Power Supply* module and its batteries to your radio case or to a piece of timber you will install in the case. Or if it won't fit inside the radio, you could mount it in some sort of Jiffy box and wire it up to the set.

If doing the latter, then you must ensure both the module and the wiring are properly insulated!

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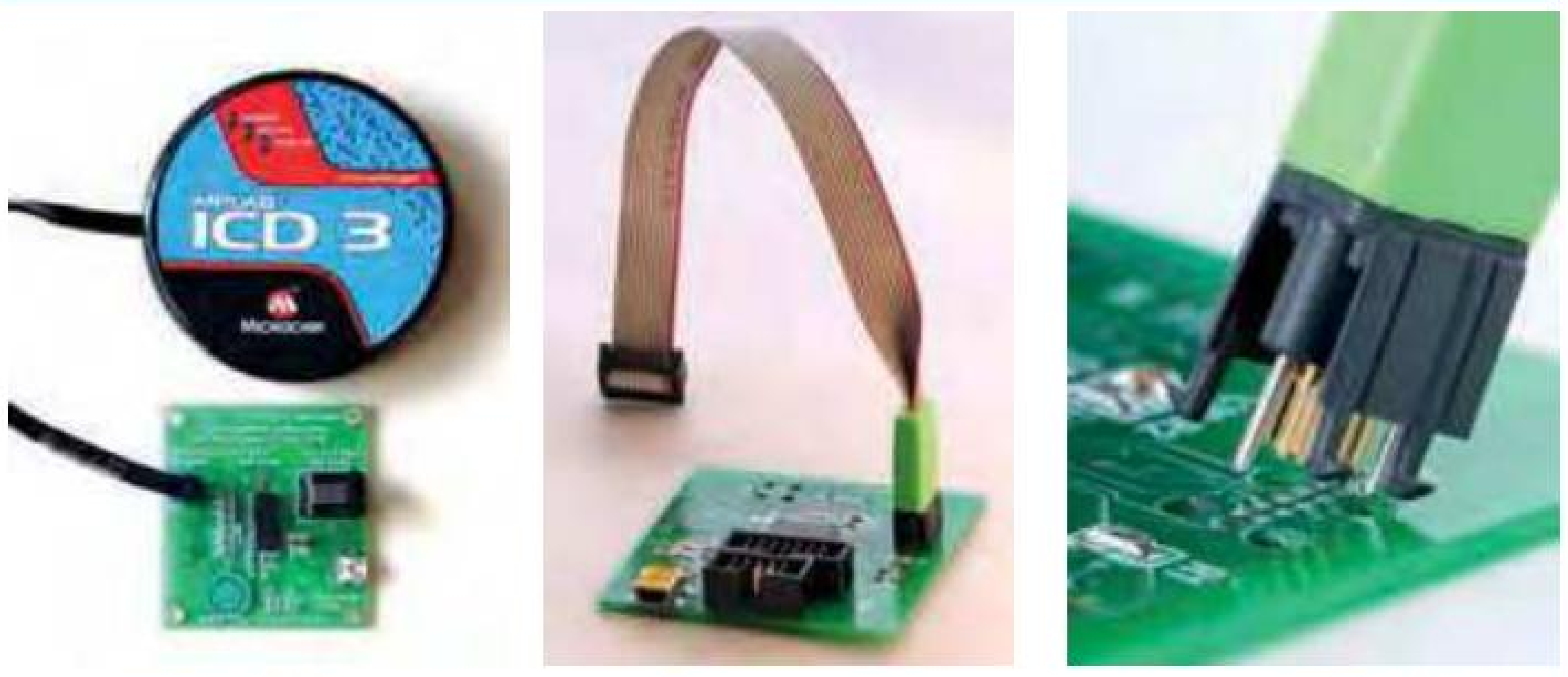

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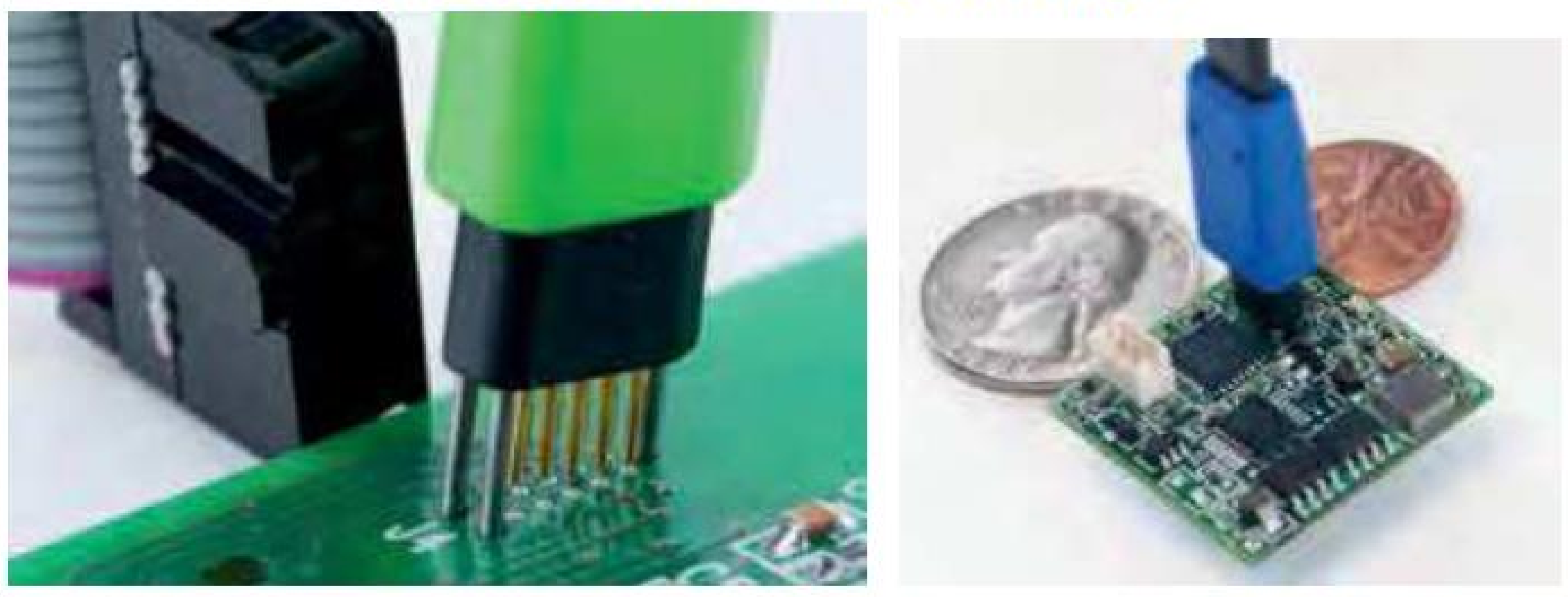

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The MiniHEART

Miniature Heartbeat Simulator

Give a favourite soft toy a beating heart! With both soft sound and a real beat, it could relax a baby, puppy or kitten for sleeping, or even help you sleep better yourself. All are possible with the *MiniHeart*!

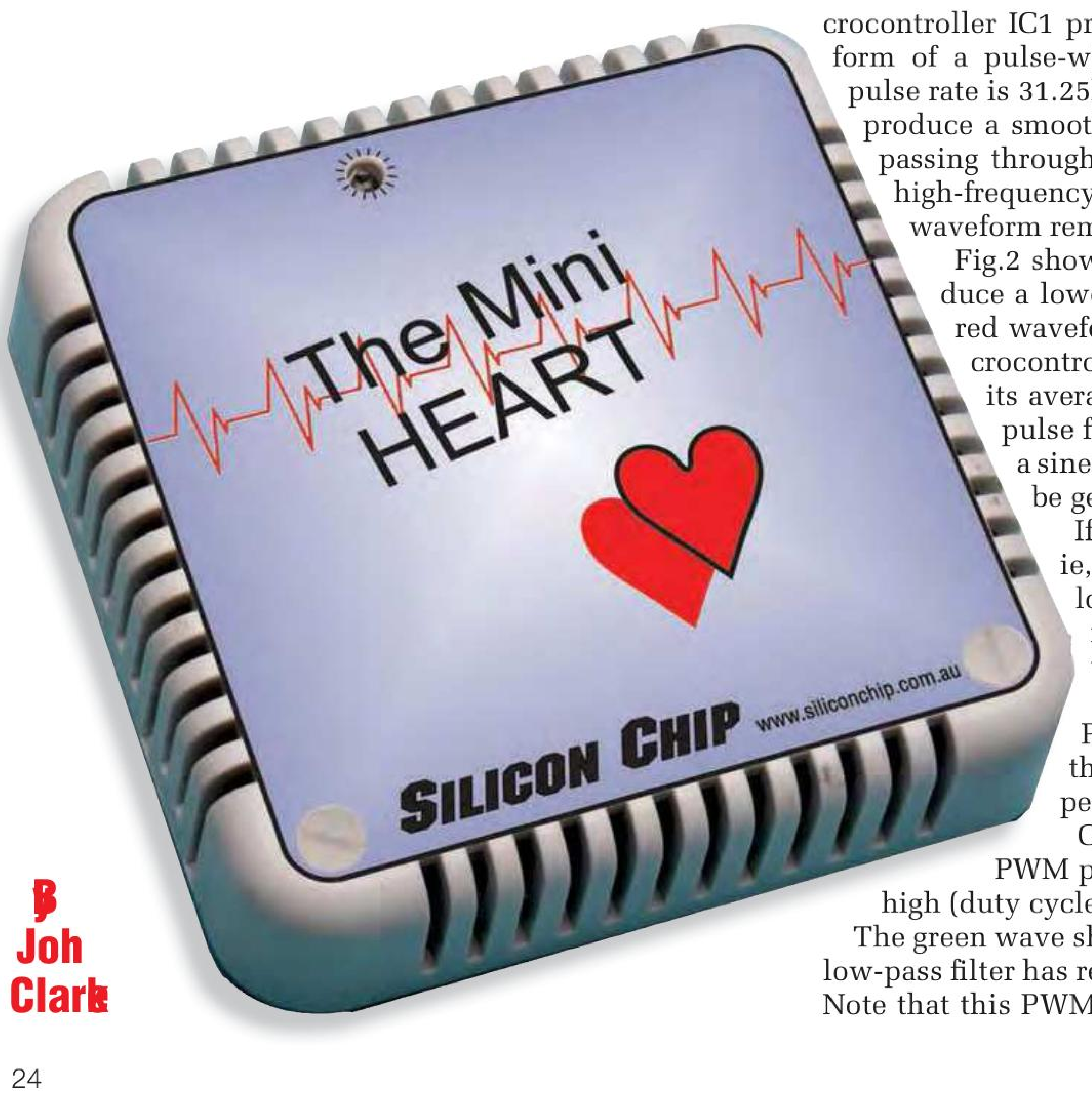
Many newborns – human babies as well as pets – are unsettled when left alone to sleep. They miss their mum, and it's lonely and frightening for them. Just being able to cuddle up to the sound of a heartbeat can help with their anxiety.

The *MiniHeart* is a small gizmo that produces a low-level soothing heartbeat sound, mimicking that of a real heart.

The beat rate can be adjusted so that it more accurately matches the rate of the heart it is to emulate, while a timer will shut off the heartbeat after a set time.

The unit is switched on and off with a toggle switch with the actuating lever only protruding slightly outside the box. This is to prevent any injury to a baby. It is fully enclosed into a plastic case that clips together, and we have added extra screw supports to make sure it stays shut. That way, the two internal AAA cells will not be easily accessed to cause a choking hazard.

We recommend enclosing the device into a cloth bag that is sewn or zippered shut. That provides an extra margin of choke hazard safety which is necessary when used with a baby. We should point out that the simulated heartbeat is not a loud sound – it is not meant to be.



By John Clarke

It is more like the subtle sound of a real beating heart; it needs to be placed close to the ear, and is felt more than heard. Think of it as a tiny heart, but in a rounded rectangular prism shape.

A loud heartbeat sound would require a large loudspeaker, properly baffled to produce bass, along with an amplifier with a reasonable amount of power. Neither of these are a feature of our *MiniHeart* simulator (but could be added externally).

Heart sounds

When listening to a heartbeat, you will hear two distinct, separate sounds, often called a 'lub' and a 'dub'. These two sounds are produced by the closing of heart valves required to pump blood efficiently.

You've almost certainly seen the classic heartbeat waveform shown on an electrocardiogram (ECG). These are the electrical signals sent to the heart muscles, and when monitored with electrodes on the skin, are useful for diagnosing heart problems. Electrode readings do not represent the sounds and vibrations made by the heart; heartbeat sounds are heard using a stethoscope.

The *MiniHeart* block diagram is shown in Fig.1. Microcontroller IC1 produces a heartbeat waveform in the form of a pulse-width modulated (PWM) signal. The pulse rate is 31.25kHz, and the pulse width is varied to produce a smoothed lower-frequency waveform after passing through a low-pass filter. This removes the high-frequency signals so that only the heartbeat waveform remains.

Fig.2 shows how a PWM signal is used to produce a lower-frequency, smooth waveform. The red waveform is the PWM output from the microcontroller, IC1, while the green waveform is its average value after filtering out the PWM pulse frequency. For convenience, we show a sinewave, although any wave shape could be generated.

If the PWM signal has a 50% duty cycle, ie, an equal period of being high and low, then the filtered voltage will sit mid-way between the high and low voltage levels.

To produce a higher voltage, the PWM signal duty cycle is altered so that the period while high is longer than the period when low (ie, duty cycle > 50%). Conversely, for a lower voltage, the PWM period is kept low for longer than it is high (duty cycle <50%).

The green wave shows the signal that appears after the low-pass filter has removed all of the higher frequencies. Note that this PWM signal is a representation only – in

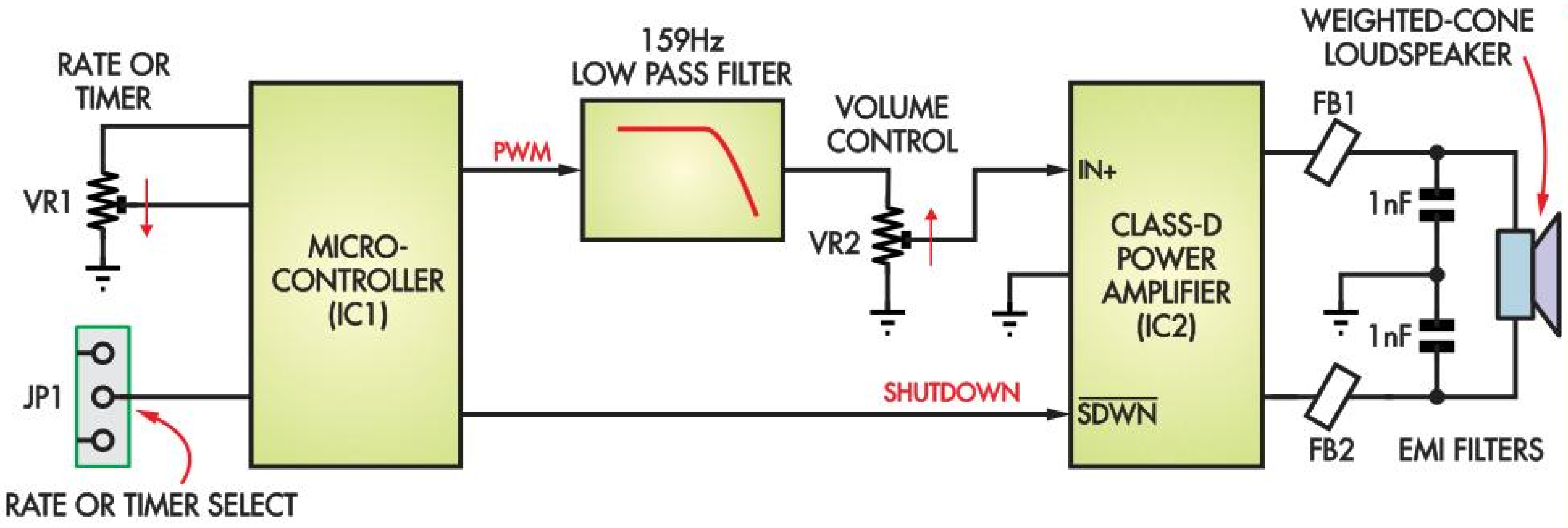


Fig.1: this block diagram shows that the MiniHeart is quite simple, using just a microcontroller and a Class-D amplifier chip to produce the sound. A basic RC low-pass filter turns the PWM output of the micro into an analogue signal for the amp, while ferrite beads and capacitors reduce EMI from the Class-D drive to the speaker

FEATURES AND SPECIFICATIONS

- **Compact size**
- **Adjustable volume**
- **Adjustable timeout and heart rate**
- **Flashing LED synchronised with the heartbeat**
- **On/off power switch**
- **Power: two AAA cells (nominally 3V), operating down to below 2.5V**
- **Current draw: 10mA average during operation, 500nA standby (typical)**
- **Timeout: adjustable from two minutes to four hours**
- **Heartbeat rate: 42 to 114 BPM**
- **Rate randomness: about 15% variation**
- **Sound frequency: 45Hz-51Hz (with a 2Hz randomness)**
- **Waveform generation method: PWM @ 31.25kHz**
- **Waveform sampling rate: approximately 1kHz**

reality, the frequency of the PWM signal is very much higher (around 700 times higher!) than the sinewave shown and cannot be reproduced to scale on the diagram.

Overleaf, we show the various scope waveforms for the *MiniHeart*. Scope1-Scope3 show the general operation. Scope1 shows a few periods of the PWM signal at around 31kHz (25µs timebase). Scope2 and Scope3 (10ms timebase) are the 'lub' and 'dub' signals produced after filtering the PWM signal.

Scope4 shows a single heartbeat with both the 'lub' and 'dub' waveforms, while Scope5 shows two heartbeats, with the pause between each heartbeat visible.

The period between each heartbeat, the frequency of the 'lub' and 'dub' waveforms and the period between the 'lub' and 'dub' waveforms have a small amount of randomness added. This is to prevent the heartbeat from sounding too artificial. It simulates the variation in heartbeat rate and timing of a real heart.

These waveforms are fed to a tiny Class-D (ie, switching) amplifier that's usually used in mobile phones and it is designed to be highly efficient. It drives the small loudspeaker in bridge mode, to maximise the power output from the limited 3V DC supply. The loudspeaker is weighted, ie, the speaker cone has a weight attached to it. This is so that low-frequency vibrations will be heard and felt.

Circuit details

The full circuit is shown in Fig.3. At its heart (!) is a PIC12F617 microcontroller, IC1. Its master clear ($\overline{MCLR}$) input, pin 4, is tied to the 3V supply rail via a 10kΩ resistor to provide a power-up reset function.

IC1 applies 3V across adjustment trimpot VR1 via its GP5 digital output; this is only brought high when the trimpot position is monitored via IC1's AN3 analogue input (pin 3). After the GP5 output is brought high, to 3V, the voltage at AN3 is converted to a digital value via IC1's internal analogue-to-digital converter (ADC). Once the value is read, the GP5 output goes low again (0V) to conserve power.

Jumper link JP1 can be placed in one of two positions; position 1 where GP1 is pulled to 0V, or position 2 where GP1 is pulled to the 3V supply. When in position 1, trimpot VR1 adjusts the heartbeat rate. When in position 2, VR1 adjusts the timeout period. The heartbeat rate can be set from 42 to 114 beats per minute (BPM). The timeout can be set between two minutes and four hours.

The heartbeat rate can be adjusted while the heartbeat is being generated, but the timeout is only checked at power-up. So after charging timeout value via VR1, power must be switched off and on again for the new timeout to take effect.

The heartbeat generation switches off after the set timeout period. This conserves power in case it is left switched on.

Note that if JP1 is removed then the pin 6 GP1 input is not held high or low. The voltage can float at a voltage anywhere between 0V and 3V. This can lead to high current consumption in IC1, reducing cell life, as digital inputs are supposed to be in one state or the other.

So IC1 checks for this condition by changing GP1 to an output and setting it to a high level for 1ms. The 1kΩ resistor charges the 100nF capacitor to 3V. Then GP1 is changed to an input, and the level is checked. If the input voltage remains high, then there is either a jumper in position 2 pulling the input high, or there is no jumper, and the input is held high via the charged 100nF capacitor.

This test is repeated with a low output. If the level changed, then JP1 is inserted. To prevent the floating input condition, GP1 is changed to a low (0V) output and left like that, minimising power consumption.

Heartbeat generation

IC1 uses its internal 8MHz oscillator to generate the 31.25kHz PWM signal at output pin 5. This is fed to a two-stage RC low-pass filter. The first stage comprises a 10kΩ resistor and 100nF capacitor to give a –3dB roll-off at 159Hz.

The second stage has the same roll-off frequency but uses a 100kΩ resistor with a 10nF capacitor. These components give an impedance which is 10 times that of the first stage filter, minimising the loading on the first stage due to the second stage. The filtered signal is fed to volume control trimpot VR2 and then to the non-inverting input, pin 3, of amplifier IC2 via a 1µF capacitor and 27kΩ resistor.

IC2 is a TPA2005D1 Class-D (ie, switching) amplifier in a tiny SMD package, measuring only 3 × 5mm. It is specifically designed for use in mobile phones where its high efficiency is crucial. The block diagram of the TPA2005D1 is shown in Fig.4.

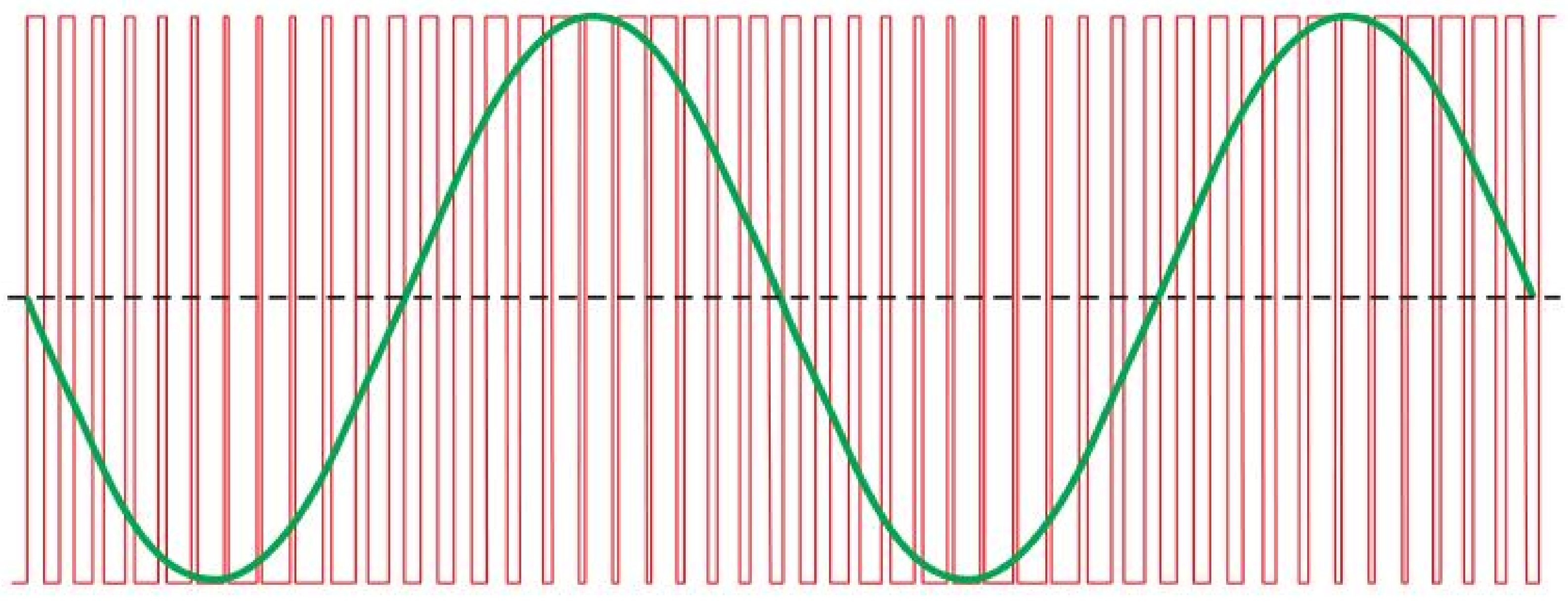
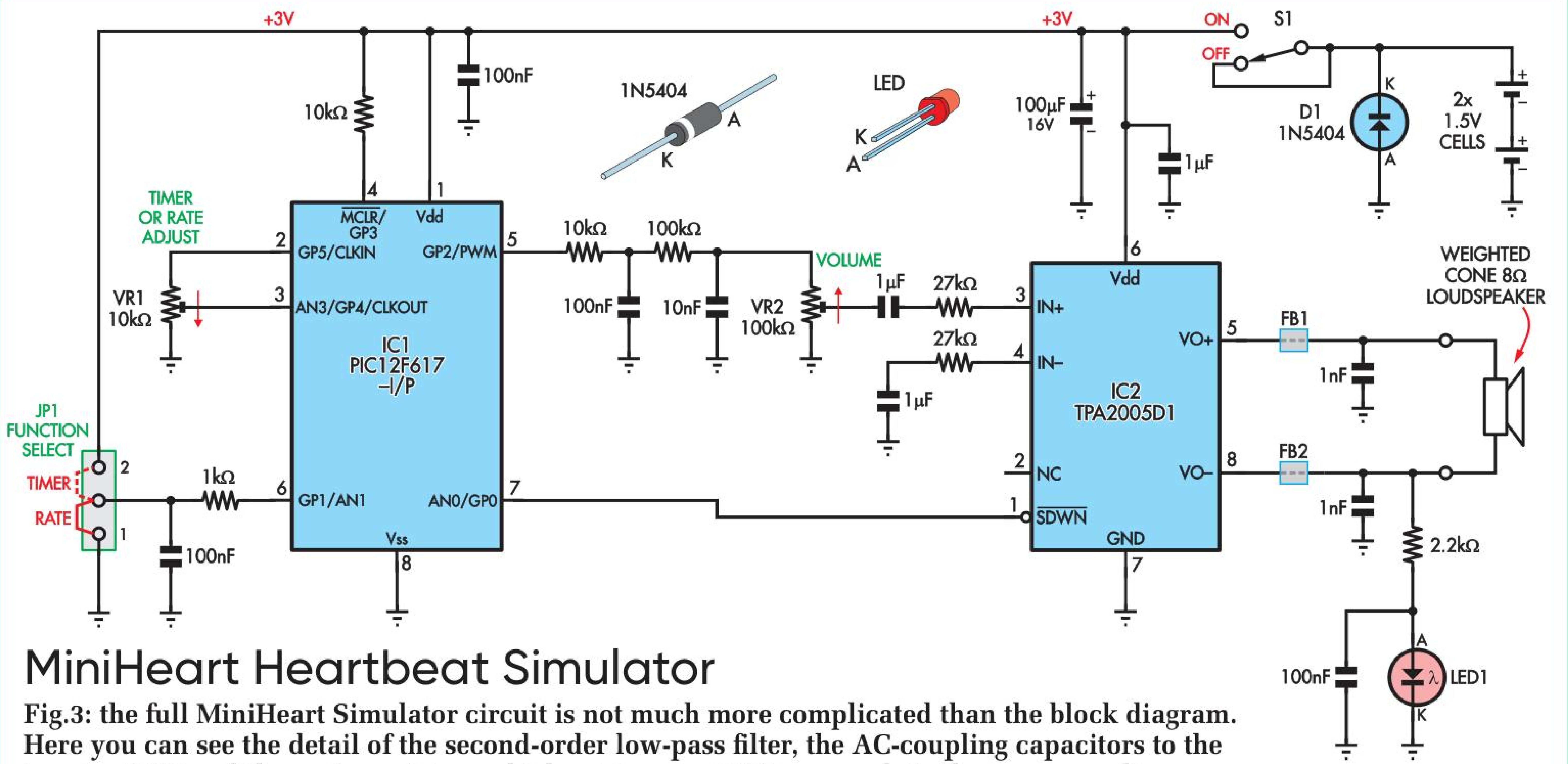

RED WAVEFORM = PWM (PULSE WIDTH MODULATION) SIGNAL
GREEN WAVEFORM = SYNTHESISED SINEWAVE (AFTER LOW-PASS FILTERING)

Fig.2: this shows how a high-frequency pulse-width-modulated 'square wave' can be fed through a low-pass filter to produce a smoothly varying, lower-frequency arbitrary waveform (shown in green). The instantaneous voltage of the green waveform equals the average voltage of the red waveform. In reality, the pulse frequency would be much higher in comparison to the reconstructed waveform.


+3V
+3V
ON
OFF
S1
100nF
10kΩ
1N5404
A
K
LED
K
A
100µF 16V
1µF
D1 1N5404
2x 1.5V CELLS
TIMER OR RATE ADJUST
VR1 10kΩ
MCLR/GP3
Vdd
GP5/CLKIN
GP2/PWM
AN3/GP4/CLKOUT
IC1 PIC12F617 –I/P
GP1/AN1
AN0/GP0
Vss
10kΩ
100kΩ
100nF
10nF
VR2 100kΩ
VOLUME
1µF
27kΩ
27kΩ
1µF
IN+
IN–
Vdd
VO+
VO–
NC
SDWN
GND
IC2 TPA2005D1
FB1
FB2
1nF
1nF
WEIGHTED CONE 8Ω LOUDSPEAKER
2.2kΩ
100nF
LED1
JP1 FUNCTION SELECT
TIMER
RATE
1kΩ
100nF

MiniHeart Heartbeat Simulator

Fig.3: the full MiniHeart Simulator circuit is not much more complicated than the block diagram. Here you can see the detail of the second-order low-pass filter, the AC-coupling capacitors to the inputs of IC2 and the series resistors which set its gain. LED1 responds to the average voltage delivered to the speaker, so it starts to light once sound is being produced.

It has differential inputs to an internal amplifier that drives the PWM section at a switching frequency of 250kHz, set by the internal oscillator. The PWM section then feeds an H-bridge circuit for driving an external loudspeaker.

The data sheet for the TPA2005 highlights two interesting points. The first is its high CMRR (common-mode rejection ratio) which supposedly eliminates the need for input coupling capacitors. But this high CMRR only applies if the amplifier is used in balanced mode, with both inputs at the same DC level.

In our circuit, we are using it in unbalanced mode, with the inverting input grounded (via the 1µF capacitor), so we need to use two input capacitors. The 27kΩ resistor for the non-inverting input, in conjunction with the internal 150kΩ feedback resistor, sets amplifier gain at about 5.5 times. Since the amplifier is a bridge type, the overall gain is double that, ie, 11 times.

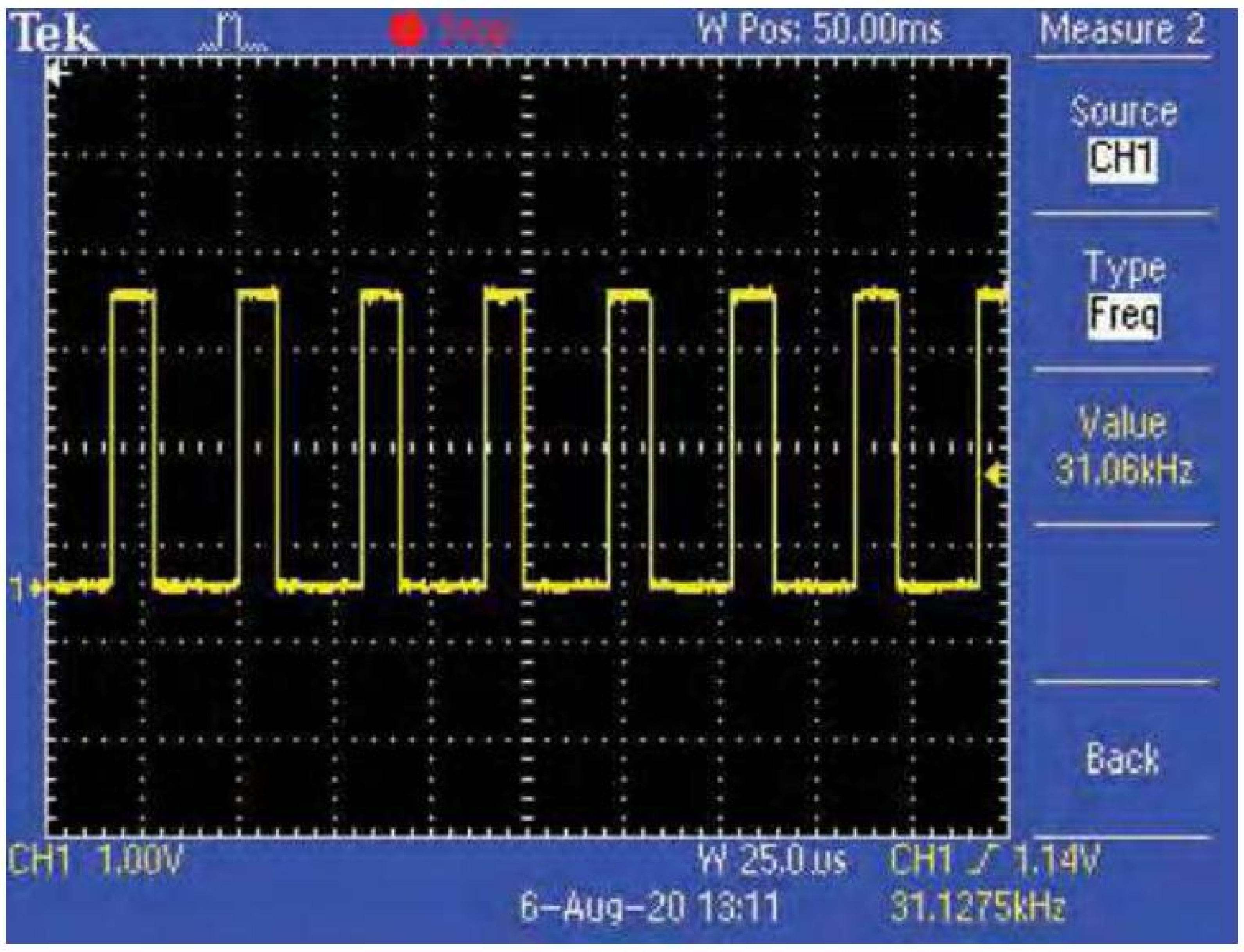
The second interesting point is that the TPA2005 can run without an output filter that would usually be required to remove the 250kHz switching signal. That is, provided the output leads are kept short. Even so, we use ferrite beads (FB1 and FB2) plus 1nF shunting capacitors to reduce electromagnetic interference (EMI).

Power supply

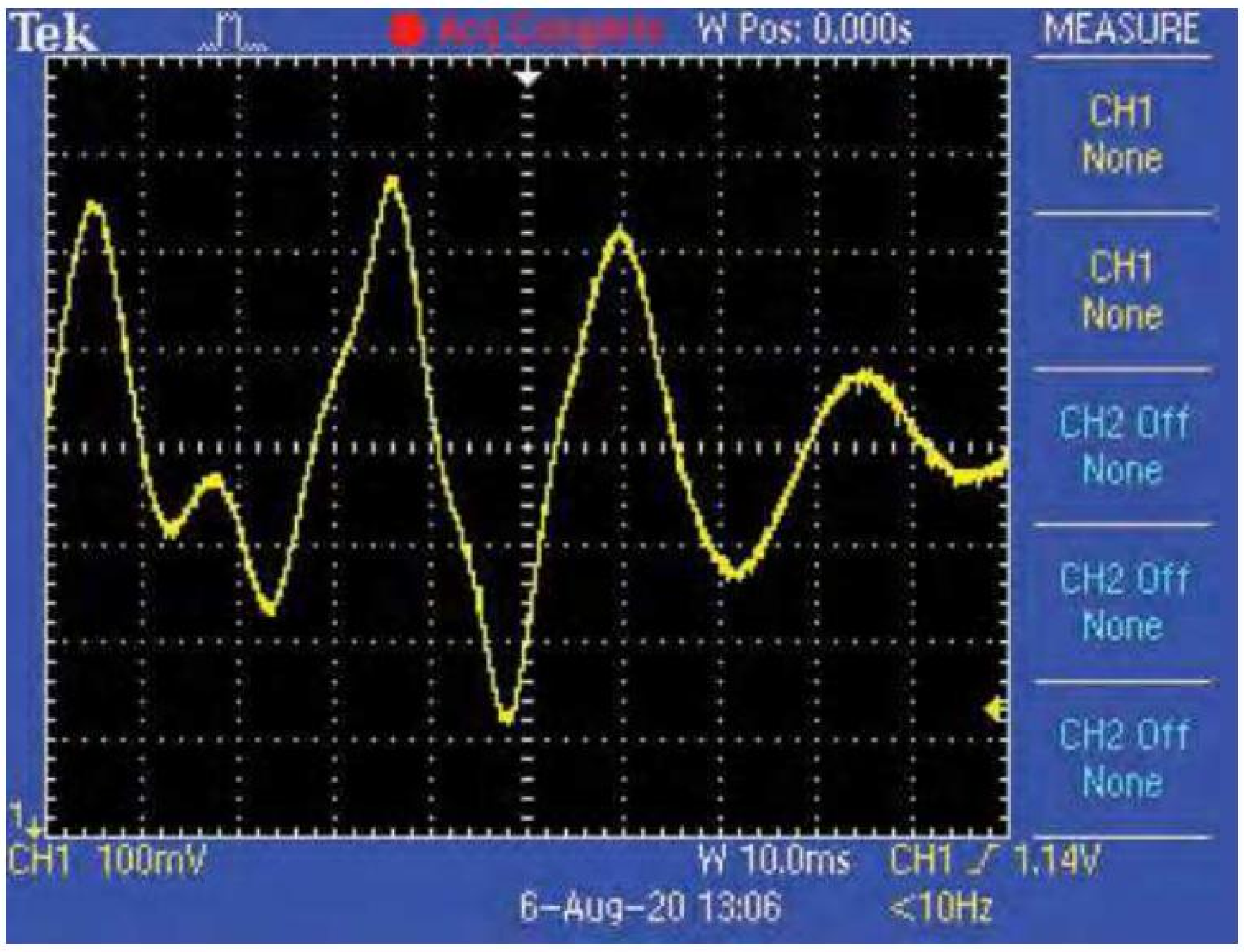
Power is from two series AAA cells to provide a nominal 3V supply, switched on or off by power switch S1. A 100µF capacitor bypasses the switched supply with a 1µF ceramic capacitor close to IC2's supply rails, and a 100nF capacitor at IC1's supply rails.

Diode D1 is included to protect against component damage if the cells are inserted with reversed polarity. In that case, the diode will conduct and limit the negative voltage to the circuit. The disadvantage is that this will quickly drain the cells, but presumably, you would notice that the device is not working and fix it straight away.

The alternative protection method, with a diode in series with the supply, drops too much voltage for this application. Even a Schottky type, with its lower forward voltage, would not be suitable and we can't justify the cost of a MOSFET in this role (which would have a lower voltage drop again).


Tek
Stop
W Pos: 50.00ms
Measure 2
Source
CH1
Type
Freq
Value
31.06kHz
Back
CH1 1.00V
W 25.0us
CH1 ⁄ 1.14V
6-Aug-20 13:11
31.1275kHz

Scope1: this shows just over seven periods of the ~32kHz PWM signal that is produced at pin 5 of IC1. The signal swing is 3V peak-to-peak, and the timebase is 25µs.


Tek
Acq Complete
W Pos: 0.000s
MEASURE
CH1
None
CH1
None
CH2 Off
None
CH2 Off
None
CH2 Off
None
CH1 100mV
W 10.0ms
CH1 ⁄ 1.14V
6-Aug-20 13:06
<10Hz

Scope2: this 'lub' signal reproduces a a real heartbeat sound, produced by filtering the PWM waveform, measured at the wiper of VR2. Note the longer timebase used here (10ms/div).

Indication

LED1 lights simultaneously with the lub/dub sounds and is driven via the VO- output of IC2. With no signal, this output sits at an average of 1.5V. This is derived by an RC low-pass filter (2.2kΩ/100nF) from the 250kHz square wave signal at pin 8 of IC2. It swings between 0V and 3V with a 50% duty cycle when idle.

The LED lights when this voltage rises above the usual LED forward voltage of around 1.8V, and that happens when the duty cycle of the pin 8 output increases above 60%.

Saving power

Since the device is powered from AAA cells, we need to minimise power usage to conserve cell life. Typically, the circuit draws an average of 10mA when producing the heartbeat. However, once the timeout period has ended, the current needs to drop to a very low level until the unit is switched off.

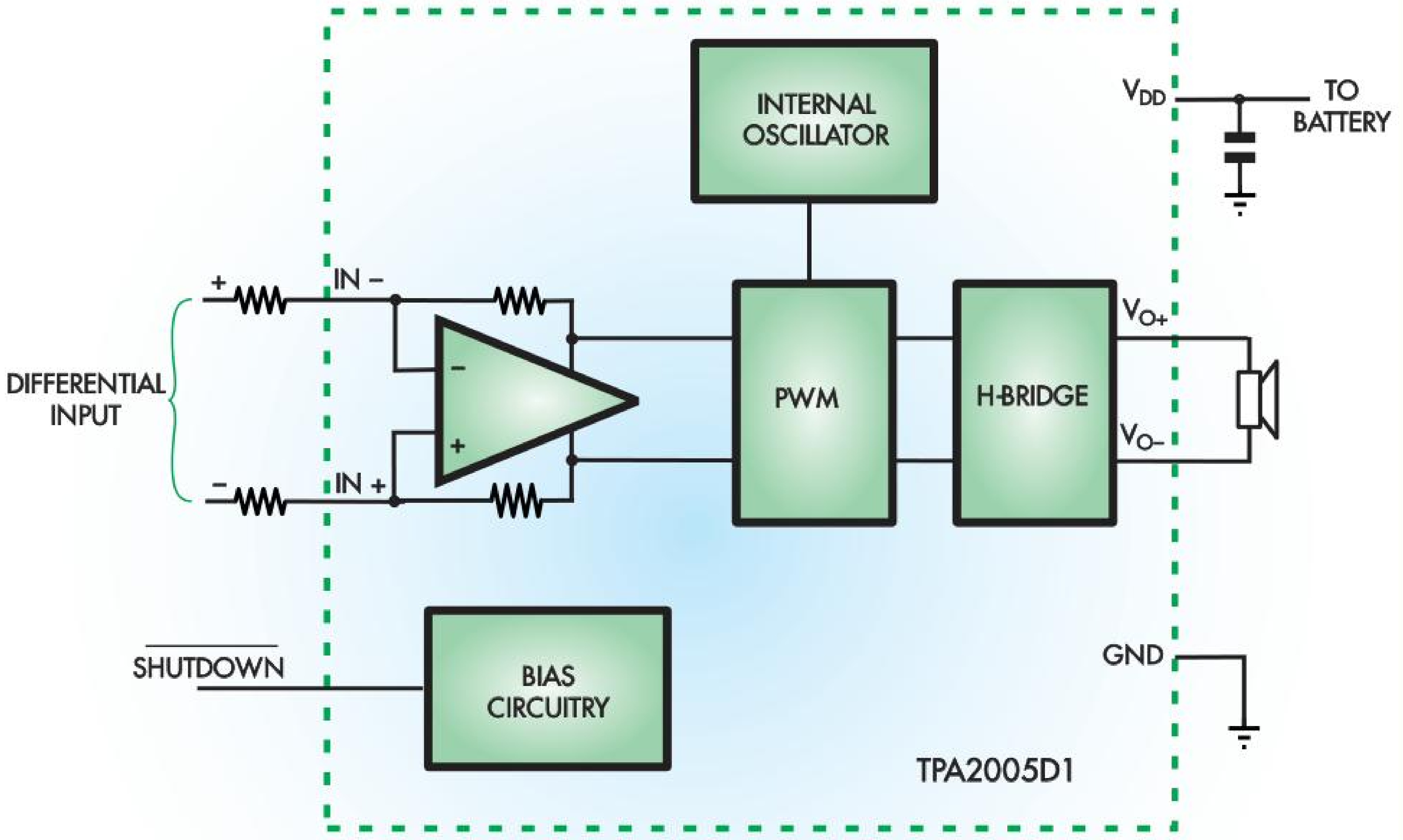


Fig.4: the internal block diagram of the TPA2005 Class-D audio amplifier IC. Its differential inputs go to a balanced analogue amplifier and then onto a PWM modulator which drives a MOSFET H-bridge, and that in turn drives the speaker. This provides high efficiency and plenty of power from a low supply voltage. As shown, it can drive a speaker in Class-D mode without a filter.

This is achieved in several ways. First, as already mentioned, there is no voltage across VR1 most of the time. Also, after the timeout period expires, microcontroller IC1 is placed in sleep mode and only draws about 150nA.

Amplifier IC2 is also switched off by IC1 taking the GP0 output low, which connects to its $\overline{\text{SDWN}}$ (shutdown) input. IC2 then draws around 500nA. We measured a 500nA current for the whole heartbeat circuit when in shutdown on our prototype (half a microamp!). The cells should last for their shelf life with such a small current drain.

Construction

The *MiniHeart* Simulator is built on a double-sided, plated-through PCB coded 01109201 which measures 70 × 73mm and available from the *PE PCB Service*. It is housed in an 80 × 80 × 20mm vented plastic enclosure.

Fig.5 shows the PCB component overlays. Begin by fitting the SMD Class-D amplifier chip, IC2. It requires a very fine soldering iron tip and, ideally, a lit gooseneck or desktop magnifier (a good LED headband magnifier also works well).

Identify its pin 1 dot under magnification, then orient it as shown in Fig.5, with pin 1 towards the speaker hole. Add some flux paste to the middle of the central pad (or liquid flux, if you don't have paste), position IC2 carefully over its pads, then tack-solder pin 4 to its pad.

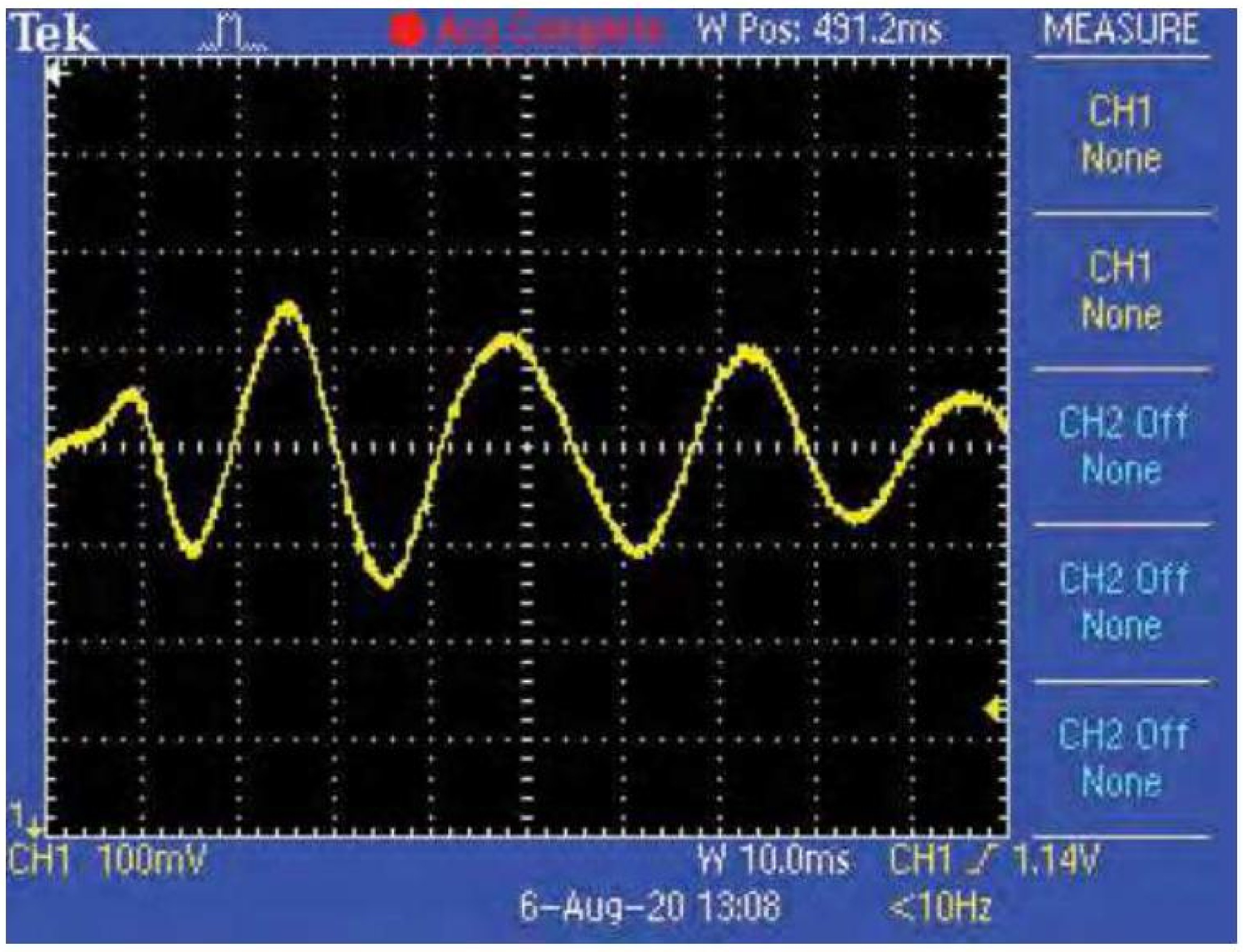
Check that the IC is still aligned with the PCB pads on both sides; remelt the solder if required. If all is OK, solder the remaining corner pins and then pins 2, 3, 6 and 7. Use solder wick to remove any solder that bridges between the IC pins.

IC2 also has a ground pad that needs to be soldered to the PCB. This can be done by feeding solder from the underside of the PCB, through the hole positioned under the IC. Use minimal solder to prevent the solder from spreading out and shorting to the IC leads.

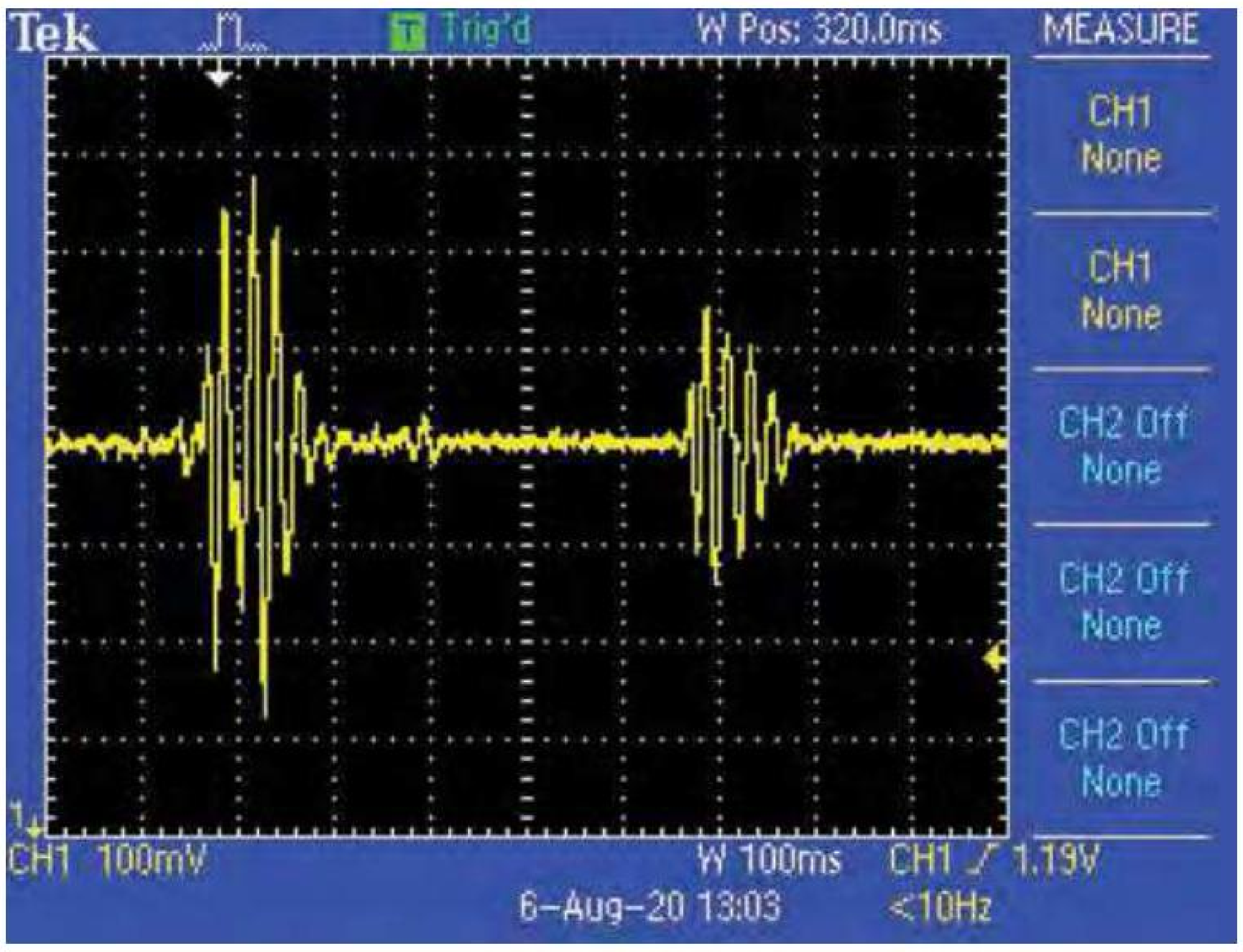
The flux you added earlier will help this solder flow onto the pad on the underside of the IC.

Now install the resistors and surface-mount capacitors. These components are located on both sides of the PCB. The capacitors are usually unmarked except on their packaging.

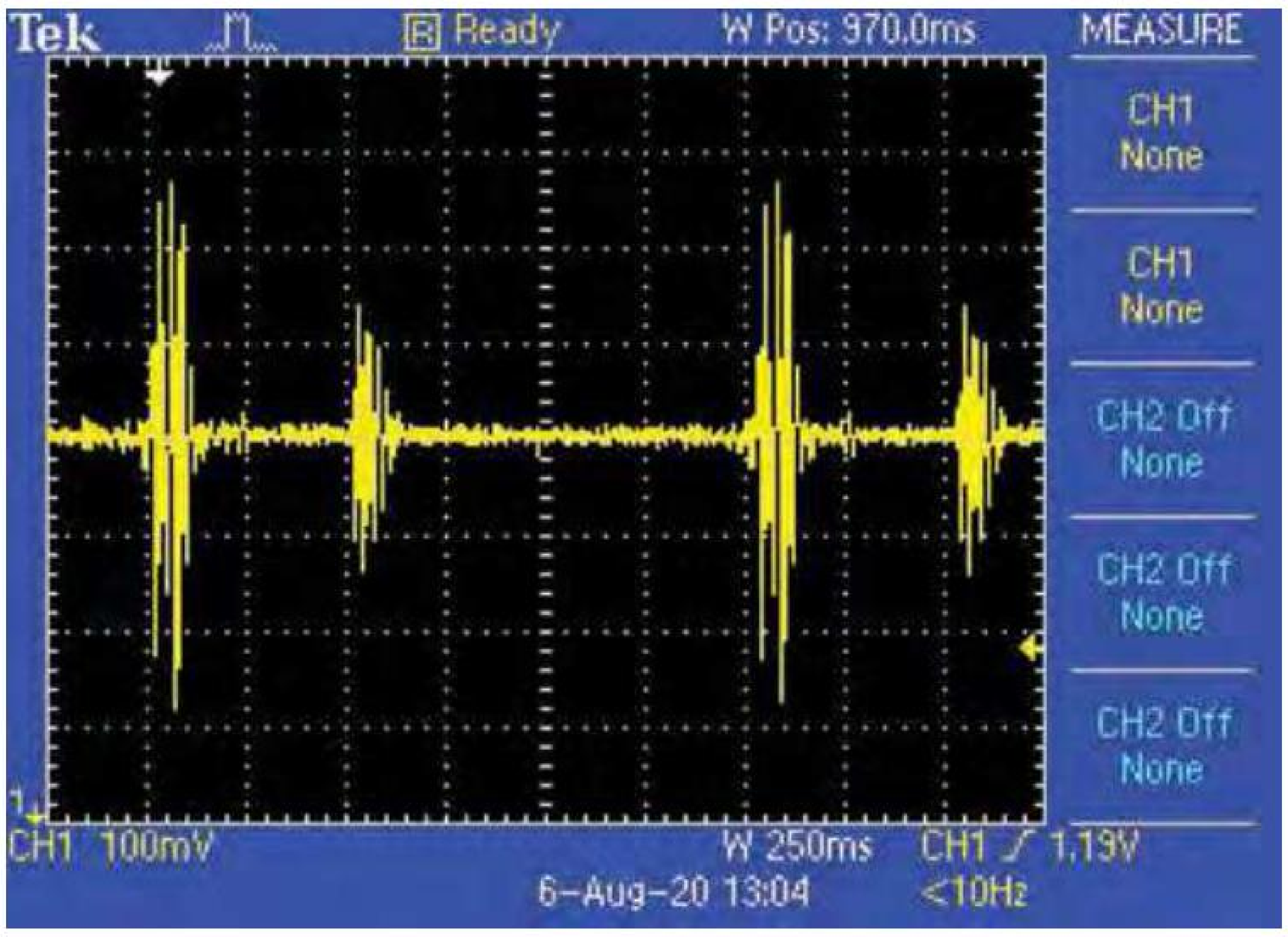
The resistors will probably be marked with a small code, as shown in the parts list. The first few digits indicate the resistance value, followed by the number of extra zeroes in the last position. So for example, a 1kΩ resistor will have the code 102 or 1001. That is a 10 followed by two zeros, or 100 followed by one zero. For 10kΩ, the code will be 103 or 1002, and so on.



Scope3: this is the 'dub' signal measured identically to the 'lub' signal shown in Scope2. Again, it is a reproduction of a real heartbeat sound.



Scope4: a single heartbeat sound with both the 'lub' and 'dub' waveform. You can see their slightly different shapes and amplitudes, and the delay between them.



Scope5: two heartbeats as shown in Scope4. With this slower timebase, you can also see the delay between beats.

Next, fit diode D1, taking care to orient it correctly. Then mount ferrite beads FB1 and FB2 by first feeding tinned copper wire through the centre hole, then inserting and soldering these to the PCB pads. Keep the wire taught when soldering to prevent the beads from being loose.

We used a socket for IC1 in case we ever want to remove it for reprogramming. Take care to orient the socket correctly (notch toward the PCB edge).

Trimpots VR1 and VR2 can be mounted now. Take care to place the 10kΩ trimpot in the VR1 position and the 100kΩ trimpot in the VR2 position. Then fit three-way header JP1 with the shorter ends of the pins through the PCB holes.

Power switch (S1) is installed in the position shown. The switch we used differs slightly from the one in the parts list in that the actuator is longer on the recommended switch. The positioning of the switch has therefore been moved further from the edge of the PCB. That way, the switch actuator will protrude from the case by the same amount as shown on our prototype.

LED1 mounts with the anode (longer lead) in the hole marked ‘A’. Solder it so that the top of the lens is 11mm above the top edge of the PCB

For the AAA cell holders, bend the wire terminals so that they stick out the sides of the holder, then bend them up to feed the leads through the holes on the PCB from the underside, and solder them on the top. The cell holders need to be oriented correctly, as shown on the overlay diagram.

The base of the cell holders should be positioned so that they sit on the enclosure base when the PCB is seated on the four mounting posts. That means that the bottom of the cell holders will be lower than the bottom edge of the PCB.

Next, fit the 100μF capacitor. Insert its leads with the longer lead through the hole marked ‘+’, then lie it over, so the capacitor body is between the LED and AAA cell holder. It must be no higher than 11mm above the top edge of the PCB. That will allow the lid to fit.

The two PC stakes for the loudspeaker connections can now be installed with the shorter end inserted into the PCB from the top side.

At this stage, don’t plug in the PIC microprocessor (IC1). You need to program the firmware (0110920A.hex) which can be loaded from the January 2022 page of the *PE* website.

Housing

Press the side clips into the case lid to release it from the baseplate. Locating flanges insert into one edge of the lid also secure it in place.

The PCB is designed to be mounted onto the integral standoffs on the base of the case. There is only one correct orientation, and that is with the two notches along the top edge of the PCB fitting into the case lid locating flanges on the base plate. The PCB is secured with small self-tapping screws into the standoffs.

We attach two 9mm-long M3 tapped spacers to the PCB to allow the lid to be screwed down. This is in addition to the side clips on the cover that hold it in place. Two screws then go into the standoffs from the outside of the lid. Attach these spacers by feeding short machine screws through the underside of the PCB into the two corner holes, then tighten the tapped spacers onto the screw shafts.

Parts List – MiniHeart Heartbeat Simulator

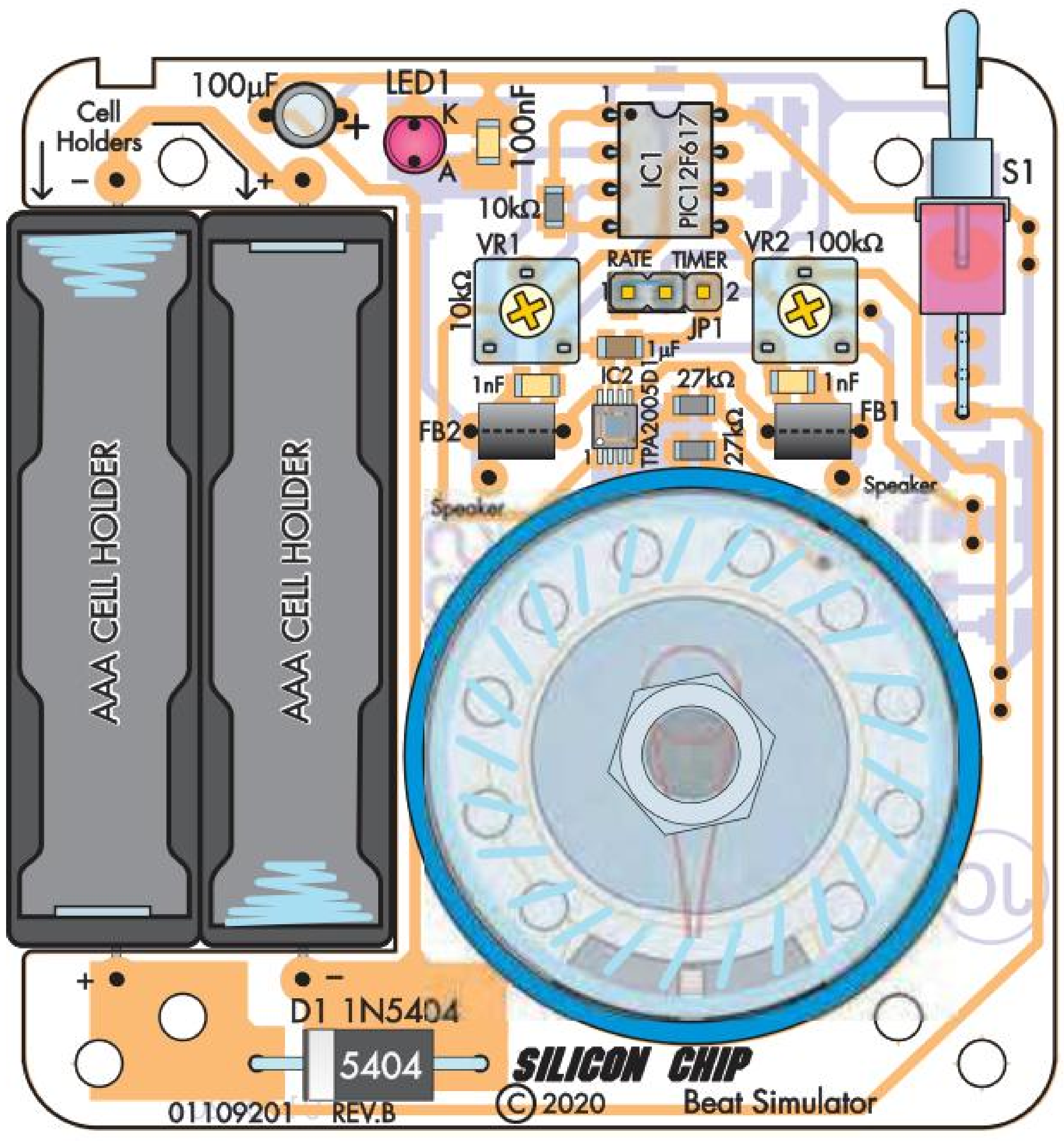
1 double-sided, plated-through PCB coded 01109201, 70 x 73mm, available from the PE PCB Service
1 Hammond 1151V4 vented enclosure, 80 x 80 x 20mm [Jaycar HB6118]
2 AAA PCB-mount cell holders
2 AAA alkaline cells
1 40mm diameter Mylar cone loudspeaker [Jaycar AS3004]
1 PCB-mount SPDT toggle switch (S1) [Altronics S1421]
1 8-pin DIL IC socket
2 ferrite beads, 4mm diameter and 5mm long (FB1,FB2) [Altronics L5250A, Jaycar LF1250]
1 3-way header, 2.54mm pitch with jumper shunt (JP1)
2 9mm-long M3 tapped spacers
2 M3 x 6mm panhead machine screws
4 No.4 self-tapping screws
2 M3 x 6mm nylon machine screws (countersunk head preferred)
1 M8 marine-grade 316 stainless non-magnetic steel nut (6.35mm tall)
1 40mm length of 0.7mm diameter tinned copper wire (for FB1 and FB2)
1 100mm length of light-gauge hookup wire (or 2-way ribbon cable or figure-8)
1 small tube of neutral-cure silicone sealant (eg, roof and gutter silicone)

Semiconductors
1 PIC12F617-I/P microcontroller programmed with 0110920A.hex (IC1)
1 TPA2005D1DGNRQ1 1.4W mono filter-free Class-D amplifier (IC2)
1 1N5404 3A diode (D1)
1 3mm high-brightness red LED (LED1)

Capacitors
1 100μF 16V PC electrolytic
3 1μF 6.3V SMD M3216/1206 X7R# ceramic
4 100nF 50V SMD M3216/1206 X7R ceramic
1 10nF 50V SMD M3216/1206 X7R ceramic
2 1nF 50V SMD M3216/1206 X7R ceramic

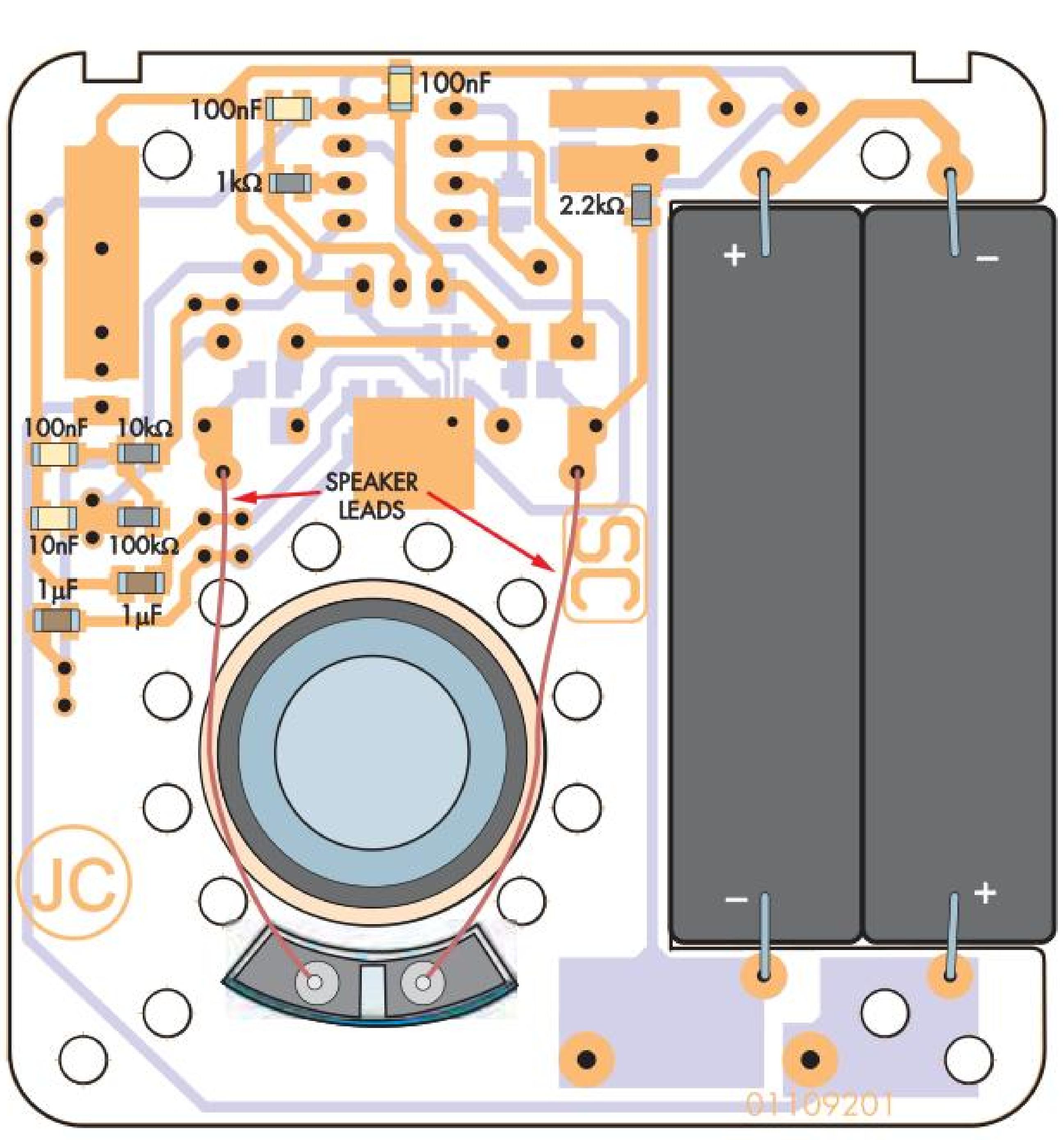
Resistors (all 1% SMD M3216/1206)
1 100kΩ (code 1003 or 104)
2 27kΩ (code 2702 or 273)
2 10kΩ (code 1002 or 103)
1 2.2kΩ (code 2201 or 222)
1 1kΩ (code 1001 or 102)
1 10kΩ mini horizontal trimpot (VR1)
1 100kΩ mini horizontal trimpot (VR2)

# a Y5V type was found to work in our prototype but X5R or X7R is a better choice

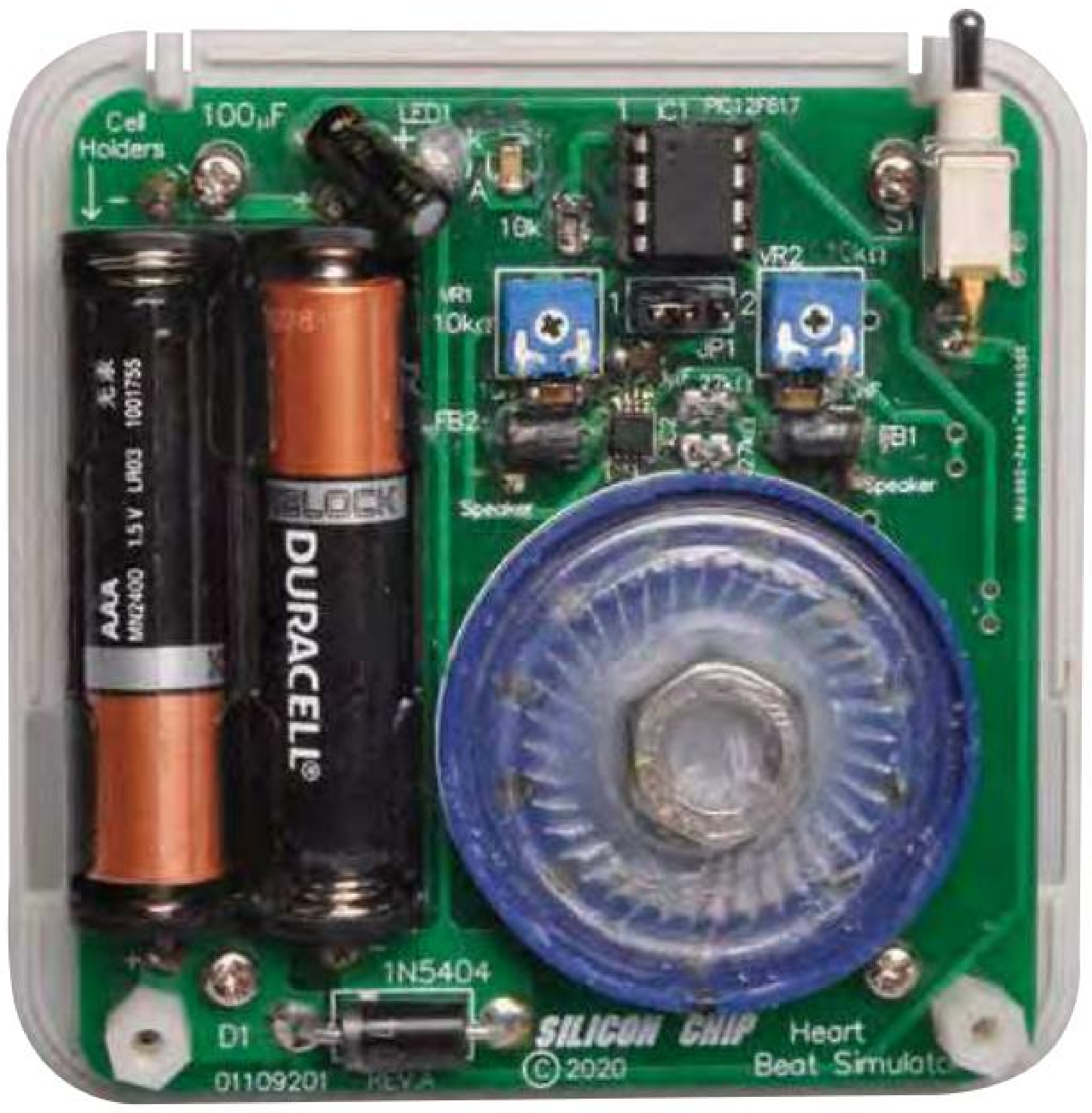


TOP VIEW

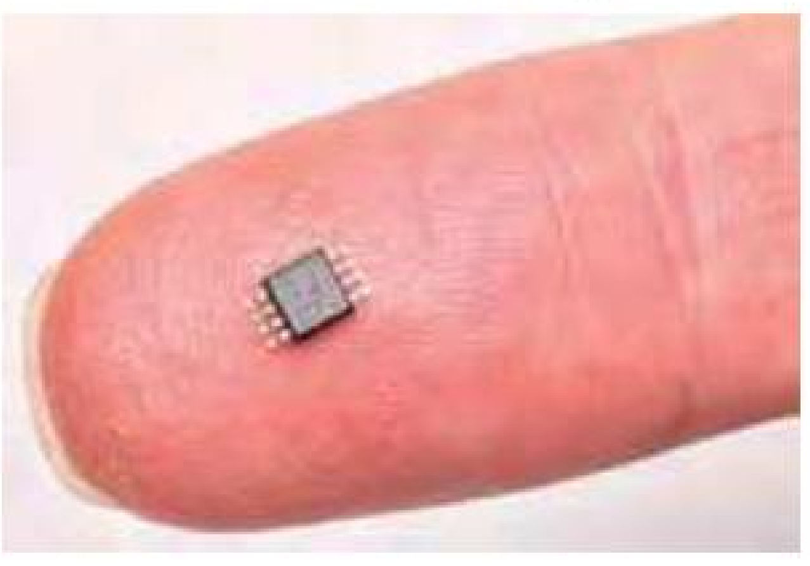
Fig.5: these (and the matching photos below), show where components are mounted on both sides of the PCB. It's generally best to fit all the SMDs to the top side (and possibly also the bottom side) before moving on to the through-hole components due to their small size and low height. Note how the speaker is oriented so that its terminals fit through the provided board cut-out, and also how the cell holder wires are bent to fit the PCB pads, fed in through the underside and soldered on top.

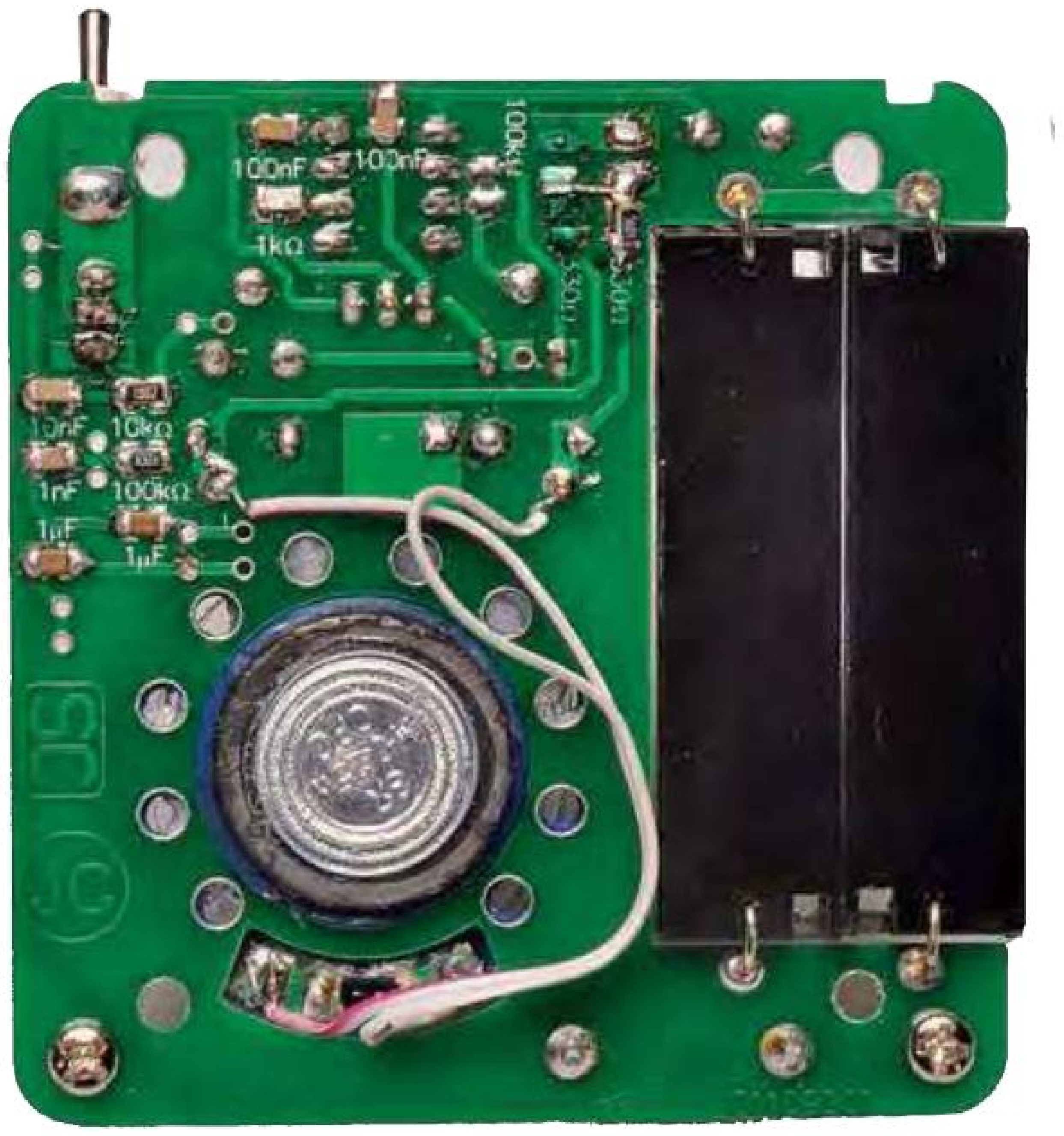


UNDERSIDE VIEW



IC1 is a normal 8-pin DIP . . . but IC2 (a TPA2005D1DGNRQ1) is tiny (it's shown below about life size). A word of warning: don't sneeze or turn a fan on if you ever want to see it again!





The template (Fig.6) shows the position of the two holes required for the securing screws. It also shows the locations for the LED hole and the two trimpot adjustment access holes. The holes for the trimpots are optional; you can omit them if you're happy to open the case if you need to make any adjustments.

The lid panel artwork (Fig.7) is also available for download from he January 2022 page of the *PE* website

Testing

Place a shorting link in JP1's position 1 and connect two wires, about 80mm long, to the two PC stakes under the PCB in readiness to solder to the miniature 8Ω speaker. We used two wires stripped from rainbow cable; mini figure-8 would also work well as well as separate hookup wires.

The loudspeaker mounts on top of the PCB with the speaker terminals in the cut-out area. The wires connect to the speaker terminals from the underside of the PCB. For the moment, the speaker will be loose.

Insert the two AAA cells and switch on the power. Check there is about 3V between pins 1 and 8 of IC1's socket.

Disconnect power and insert the programmed PIC in its socket, making sure it is oriented correctly (the notch toward the edge of the PCB). Reapply power and the speaker should start to move in response to the 'lub dub' sound. If not, make sure that VR2 is adjusted at least partly clockwise. Adjust further clockwise for more sound.

Note that the sound will have an approximate 1kHz background tone. That's because, even though this tone is filtered out in the circuitry, the speaker is much more efficient at producing 1kHz compared to the approximately 47Hz 'lub dub' sounds. Also note that you won't really hear the 'lub dub' sound, but you will feel it if you place a finger at the centre of the loudspeaker cone.

The loudspeaker cone needs to be weighted to make the heartbeat audible and to prevent the reproduction of higher frequency tones. To do this, we use an M8 stainless steel (non-magnetic) nut as a weight on the speaker cone. A non-magnetic nut must be used; otherwise, the speaker cone would be pressed against the magnet of the speaker by the nut.

We get away with this because the speaker cone is made from Mylar and so it is quite strong. This means that the central speaker coil is still centred within the magnet gap even with extra mass.

To attach the nut, apply a smear of neutral-cure silicone sealant (roof and gutter silicone is ideal) to one side of the nut and affix centrally on the speaker cone. Additional silicone is required to fill the inside of the nut, making sure it is filled down to the cone. Keep the silicone flush with the top face of the nut. Also apply a thin layer around the speaker cone.

It's also a good idea to secure the ferrite beads (FB1 and FB2) using some of the silicone to hold them to the PCB. Only a small amount is necessary. This will prevent them from rattling and adding obscure sounds to the heartbeat.

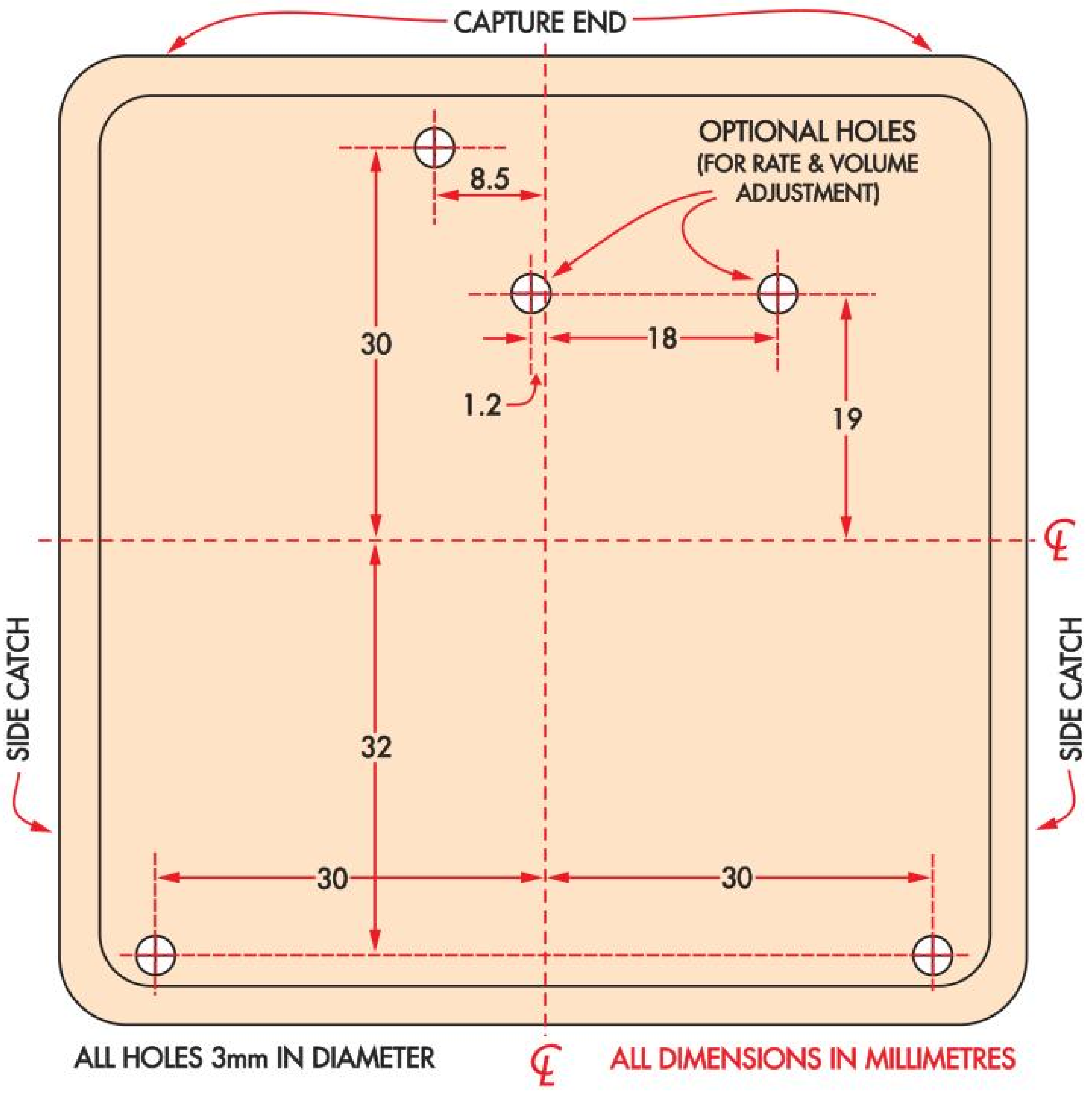

CAPTURE END
OPTIONAL HOLES
(FOR RATE & VOLUME ADJUSTMENT)
8.5
30
18
1.2
19
32
30
30
SIDE CATCH
SIDE CATCH
℄
℄
ALL HOLES 3mm IN DIAMETER
ALL DIMENSIONS IN MILLIMETRES

Fig.6: this drilling diagram shows the locations of the 3mm LED hole, two 3mm lid attachment holes (along the bottom) and optional holes to access the adjustment trimpots without having to remove the lid.

Likewise, the loudspeaker is secured to the PCB with some silicone around the central magnet, where it fits into the PCB hole.

Note that the speaker needs to be positioned correctly, with the wire entry points positioned over the PCB cut-out and with the back of the speaker magnet resting on the base of the case.

The PCB should be temporarily positioned on the integral standoffs in the case while the silicone cures. This way, the speaker will be at the correct height above the PCB.

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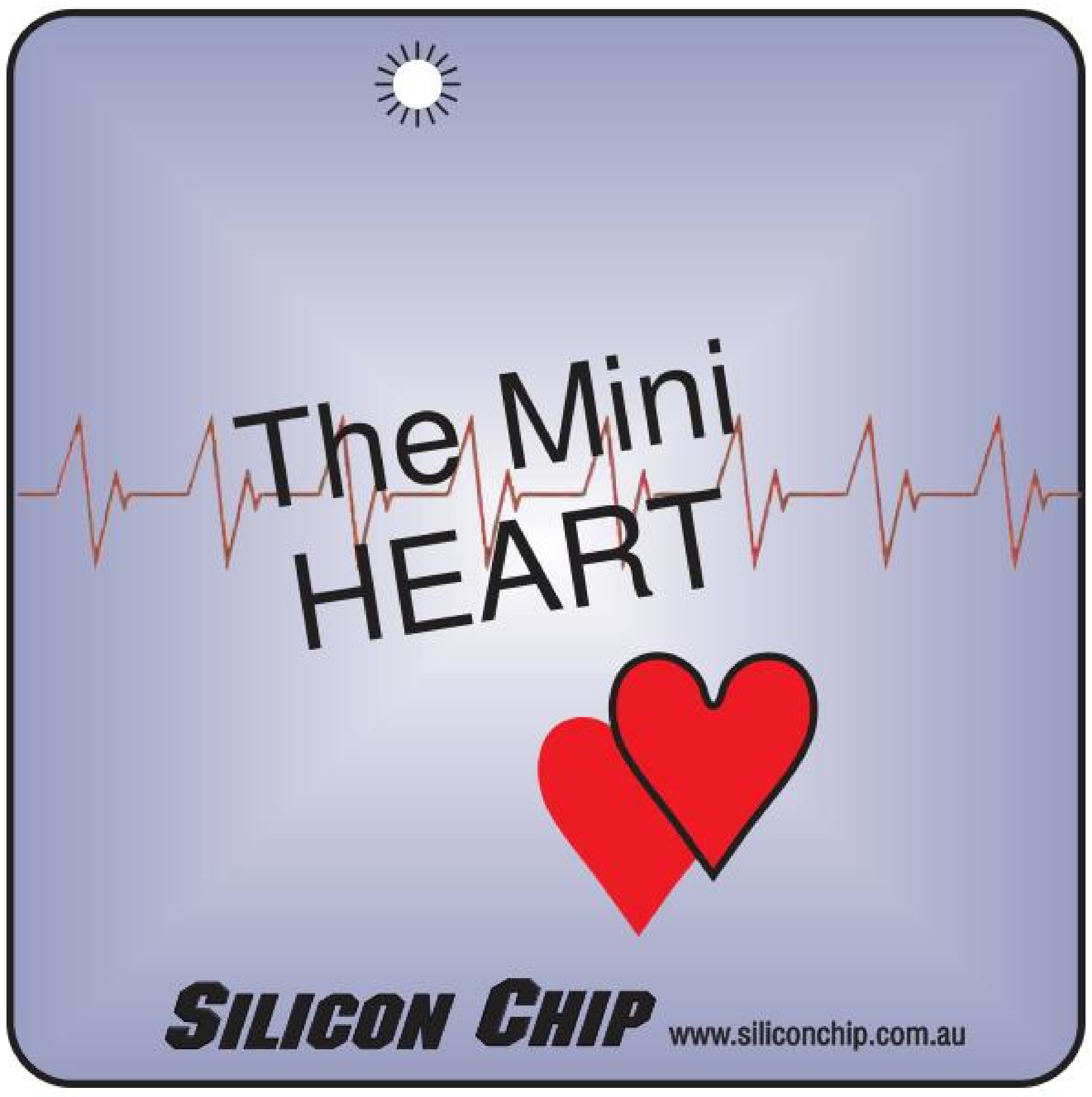

Fig.7: the 'front panel' artwork, which has a hole provided for the LED. You can download a PDF of this artwork from the January 2022 page of the PE website.

Using it

Adjust the timeout period so that the heartbeat sound lasts for the length of time you require. This is done with JP1 in position 2. To do this, move JP1 into position 2 with the power off and set the required time. Full clockwise adjustment of VR1 gives a 4-hour timeout. The mid position is two hours and mid-way between fully anticlockwise and mid-way is about one hour.

Set the timeout and then switch on the power. The timeout period will be recorded. Any further adjustment of VR1 with the power on will be ignored. It is only the setting of VR1 at power-up when JP1 is in position 2 that is recorded. The setting is stored in non-volatile Flash memory and remembered for use next time.

When jumper 1 is in position 1, the heartbeat rate can be adjusted. This can be changed with power on, from 42 to 114 beats per minute. The setting is also stored in Flash memory, and the last setting will be used should the unit be powered up with JP1 in position 2.

The volume is set using VR2. However, the drive to the loudspeaker will become distorted if VR2 is rotated too far clockwise, so a position less than halfway clockwise should be used.

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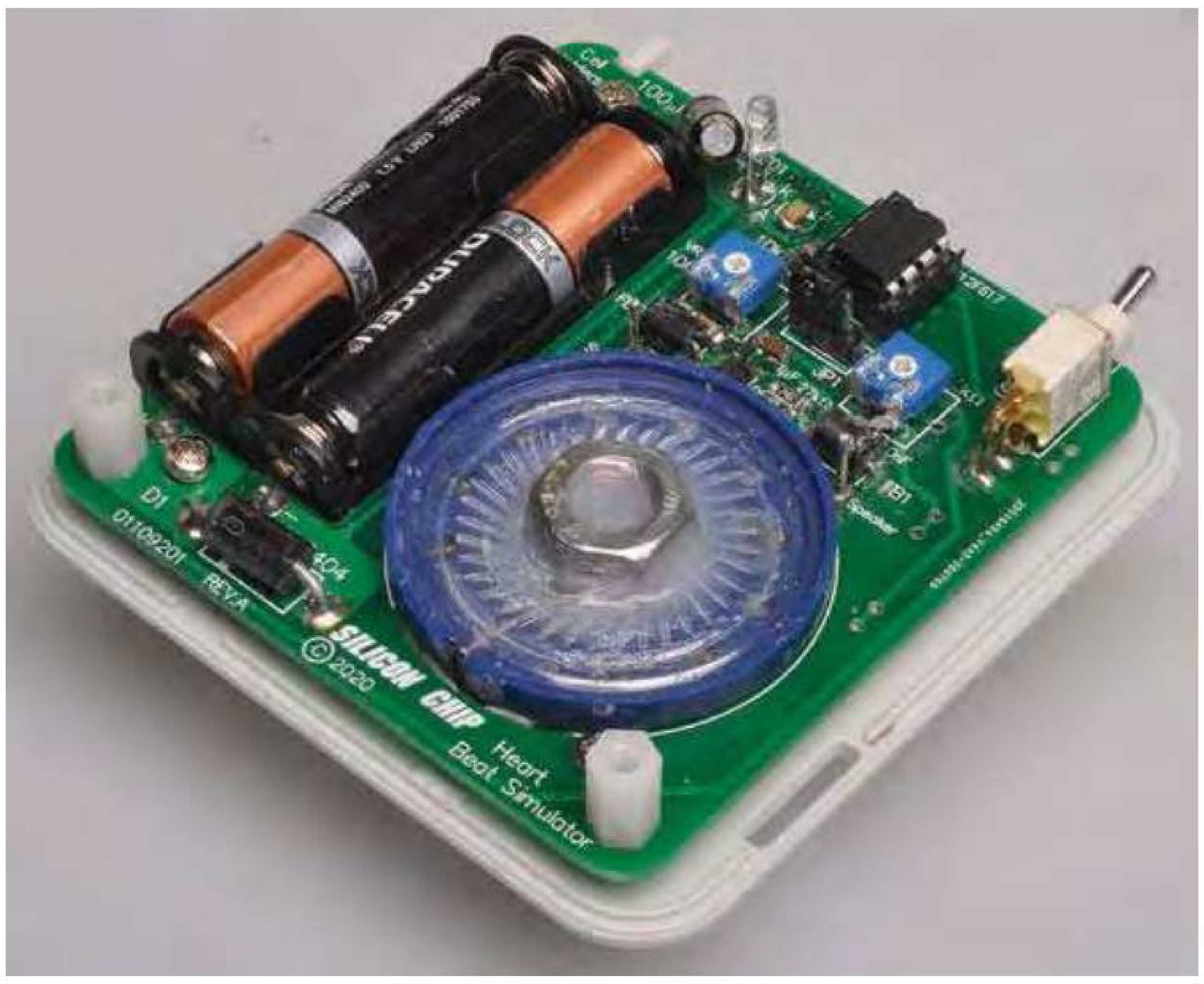
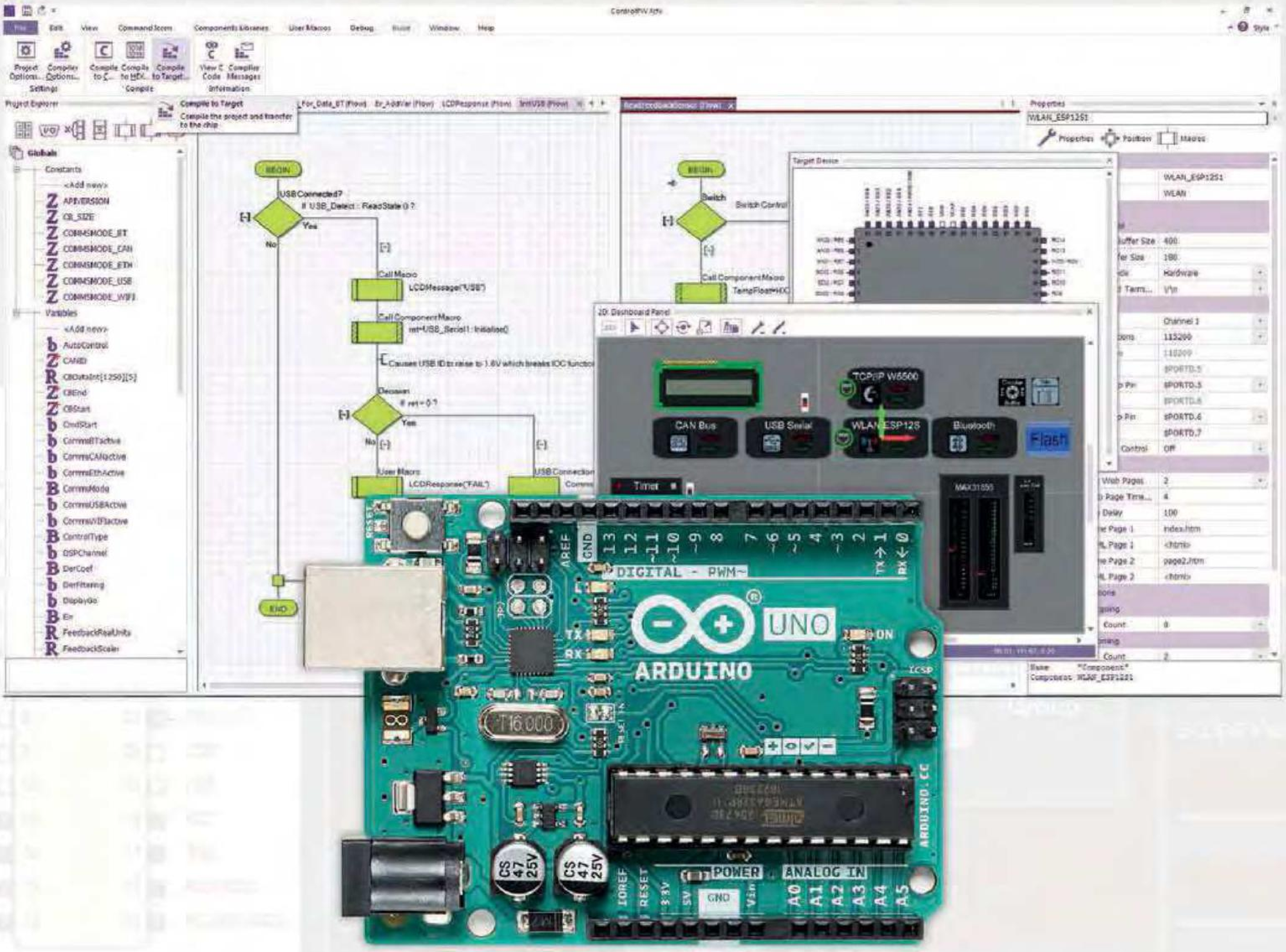


This view shows how the PCB is secured to the case lid but more importantly, shows the 'damper' glued to the mica speaker diaphragm (in this case, a stainless steel nut). Don't be tempted to use a mild steel nut: they're magnetic and will not work in this role.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Part 2 – by Phil Prosser

As described last month, this add-on board for the *USB SuperCodec* provides two balanced inputs with four attenuation options: 0dB, 10dB, 20dB and 40dB. It will fit in with the *SuperCodec* (in the same instrument case), resulting in a sleek all-in-one recording and measurement instrument. Now let's get onto building it!

All of the components shown and described in the circuit last month fit on a single PCB which is quite quick and straightforward to build. The wiring to connect the two boards isn't too difficult to make up either, consisting of one stereo shielded cable and one three-wire DC supply lead. The case end panels need to be drilled differently than what was described for the original *SuperCodec.*

The first step in assembly is to mount all the main components on the printed circuit board. Before assembling it, if you have an accurate resistance meter, you may wish to measure the 0.1% tolerance resistors and find the best matched sets among those you have purchased. However, that is optional. As long as they meet the specified tolerances, the performance of your unit should be close to that of our prototype; it might even exceed ours, if you're lucky.

PCB assembly

We have made an effort to use only through-hole components for ease of construction and made room for relay switching of the attenuators rather than a rotary wafer switch.

Before starting construction, you will need to determine your desired input impedance. Review last month's article and then refer to the parts list to see which parts you will need for your selected option. The add-on board (coded 01106202, available from the *PE PCB Service*) measures 99.5 × 141.5mm. Refer to overlay diagram Fig.9 during construction.

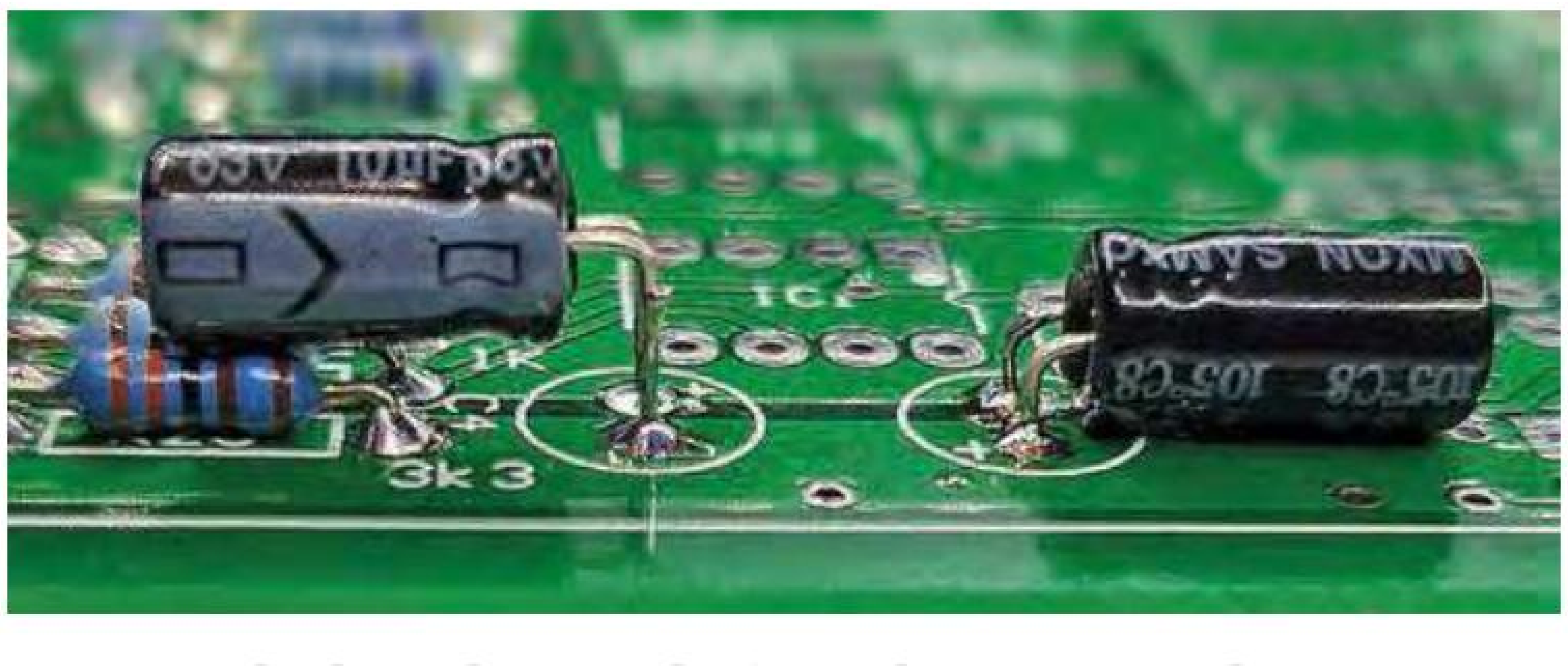
Start by loading the low-profile components: ferrite beads FB1-FB4 and all resistors. Make sure that the 0.1% types go in the specified locations.

Tip: if you can match resistors between the 'hot' and 'cold' legs of each channel, you will get a useful improvement in common-mode rejection but this may not be possible depending on the resistors you purchase and the accuracy of your ohmmeter.

If your ferrite beads are the loose types, feed resistor lead off-cuts through them. Keep them tight on the board, and it's a good idea to use dobs of neutral cure silicone sealant or similar glue to stop them from moving and rattling.

Next, mount all the zener diodes and the 1N4148 signal diodes. Be careful to orient the diode cathode stripes as shown in Fig.9, as they don't all face the same way.

We have specified 3.9V zeners for ZD3 and ZD4, but any value from 3.3V to about 4.7V should work, as these just establish a protection voltage.



Because the board is a tight fit in the *SuperCodec* case, some electrolytics must be installed horizontally, as shown here. Indeed, in some cases, they lie horizontally spaced above other components.

Now install the electrolytic capacitors, which are also polarised; their longer leads must go into the pads marked with + symbols. The 10µF capacitors must be laid down flat as shown in the accompanying photograph, or selected as very low profile units. This is important, as we will be squeezing this board into the box with the USB interface, ADC and DAC.

Next, fit the remaining capacitors (plastic film and ceramic). Remember to use 10µF plastic film capacitors for the coupling caps if you've chosen resistors for a 10kΩ input impedance, or 1µF for a 100kΩ input impedance. These too must be laid over on their sides to clear components on the other board.

After that, solder the six NE5532 ICs and eight relays. The IC and relay orientations are critical. All the relays are orientated with pin 1 away from the input connectors, while all the op amps have pin 1 toward the inputs.

You can mount the ICs on sockets, but we prefer not to as the contacts can oxidise over time, leading to poor connections. If using sockets, solder them with the orientations shown, then straighten the IC pins and carefully push them fully into the sockets.

Mount the connectors next, followed by the input select switch. The two right-angle polarised headers can be soldered from the top side, but it's a good idea to solder the pins on the bottom too. Follow with the two 6.35mm TRS sockets.

Make sure these are the specified low-profile types and that they are fitted snug to the board.

Your add-on board is now be finished. The three boards are connected by several cables, which we will now describe.

Making the internal cables

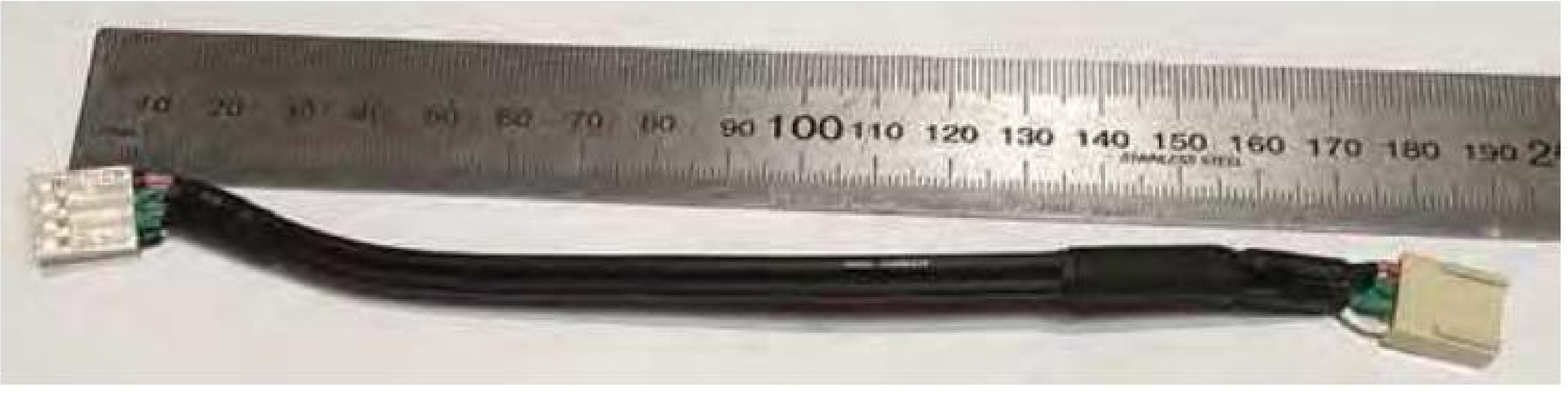
The output of the *Balanced Input Attenuator* board is connected to the *USB Sound Card* board by a 180mm length of shielded cable. To make this, cut a piece of figure-8 shielded cable to 180mm, strip 18mm off the sheath at each end, twist the screen wires together and apply the 2.5mm diameter heatshrink to these.

Then put the 5mm heatshrink over each coax line and shrink, as shown in the photograph below. Crimp pins on each end and insert them into the 4-way plug as shown. The middle two pins are earth while the outer two pins are for the signal wires.

Preparing the SuperCodec board

If you haven't already built the *USB Sound Card* board, as per the series of articles in the last three issues, do that now. But note that there are two things you need to do slightly differently when building it:

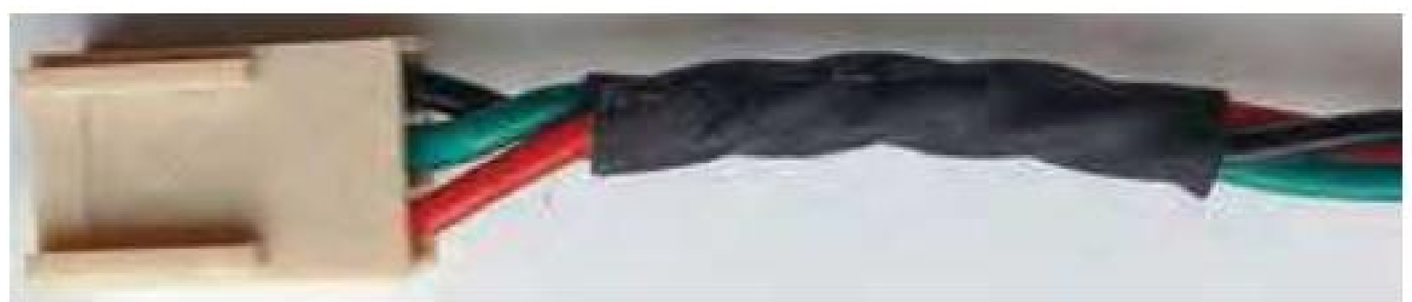
1) Do not mount the two 6x2-pin 2.0mm pitch header sockets on the back of the board for the MCHStreamer. We will instead be soldering pigtailed connectors to these locations, to allow us to mount the MCHStreamer above the USB Sound Card board.
2) When building that board, make sure the voltage regulator that is not mounted on a heatsink is pushed right down onto the PCB, or it may foul the *Balanced Input Attenuator board.*



The output cable should be 180mm of twin screened coaxial cable. The middle two pins are the shields.

Having completed that board (minus the MCHStreamer connectors), the next step is to solder a power cable to it, which will plug into the *Balanced Input Attenuato*r board and power it.

To do this, take 100mm lengths of red, green and black medium-duty hookup wire and attach them to crimp pins, then push these into the power header, as shown in the photograph below. Red (positive) is at the right-hand end, ground (green) in the middle and black (negative) at the left.



Power cable and header for the attenuator board.

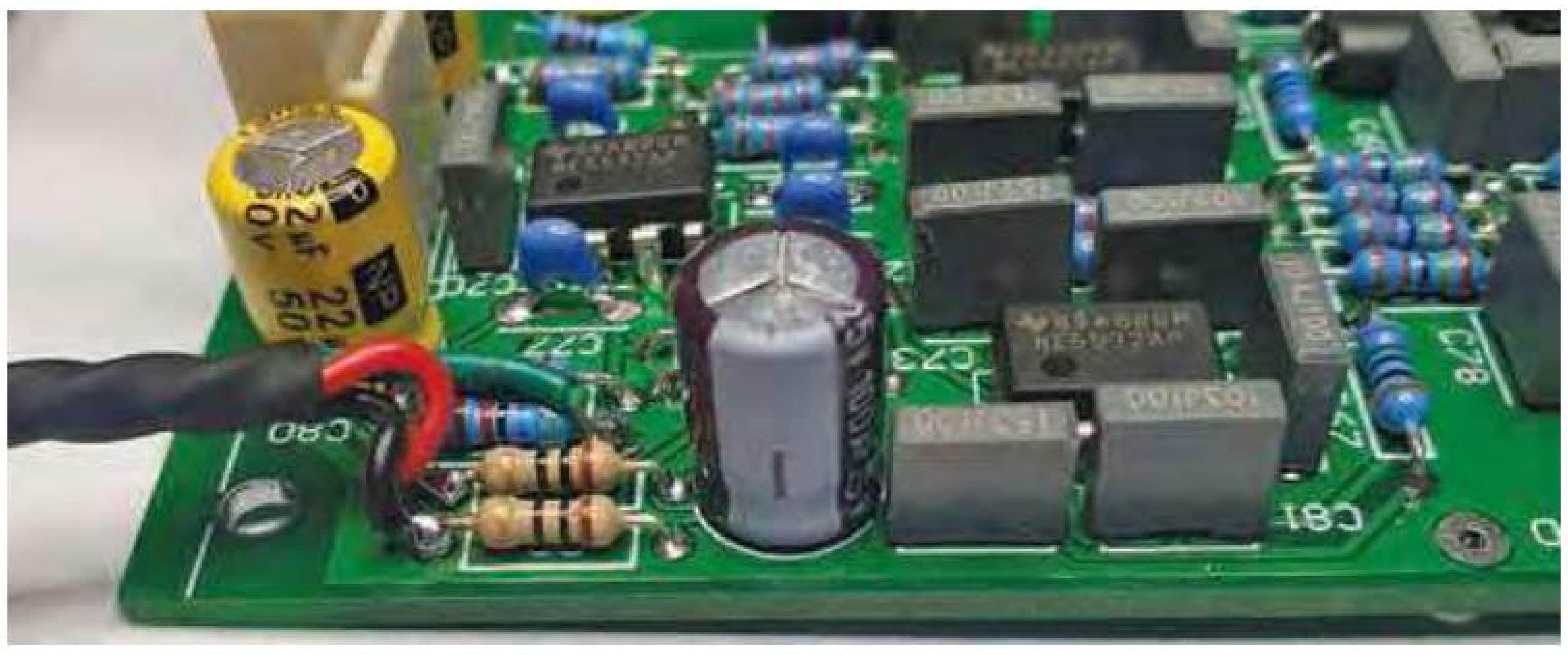
Sleeve the whole cable in a heatshrink tubing sheath, with around 3cm of each wire protruding, then strip the insulation back by about 5mm on each wire and tin the ends. These bare ends are then soldered to component pads on the *SuperCodec PCB*. The photo below shows where they go.

Check you have the wires in the right spots! The black wire goes to the end of the corner-most 10Ω resistor that is closest to the board edge; the red wire goes to the same end of the adjacent 10Ω resistor; the green to the end of the adjacent 5.6kΩ resistor that is furthest from the board edge.

Once you've done this, double-check that the wires go into the appropriate positions on the plastic block at the other end; otherwise, there will be trouble when you plug it in later.

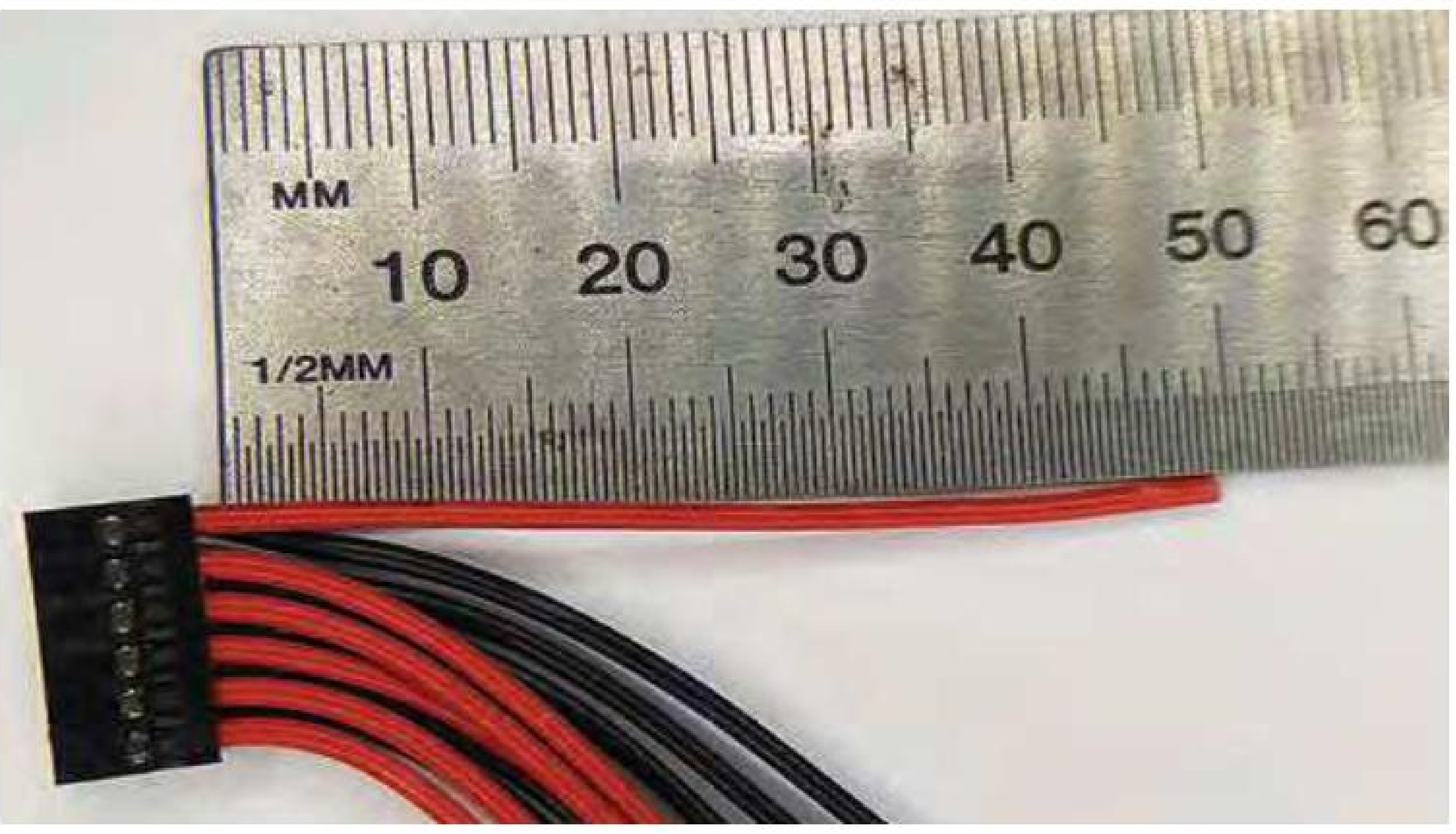
Connecting the MCHStreamer

The next step is to connect the MCHStreamer to the *SuperCodec* board, but we are doing it differently than for the standalone *USB SuperCodec*. Otherwise, it is impossible to fit the *Balanced Input Attenuator* in the same case. Rather than plugging the MCHStreamer directly onto the *SuperCodec* board, it connects via two 12-way plugs that connect to the board via sets of 12 flying leads.

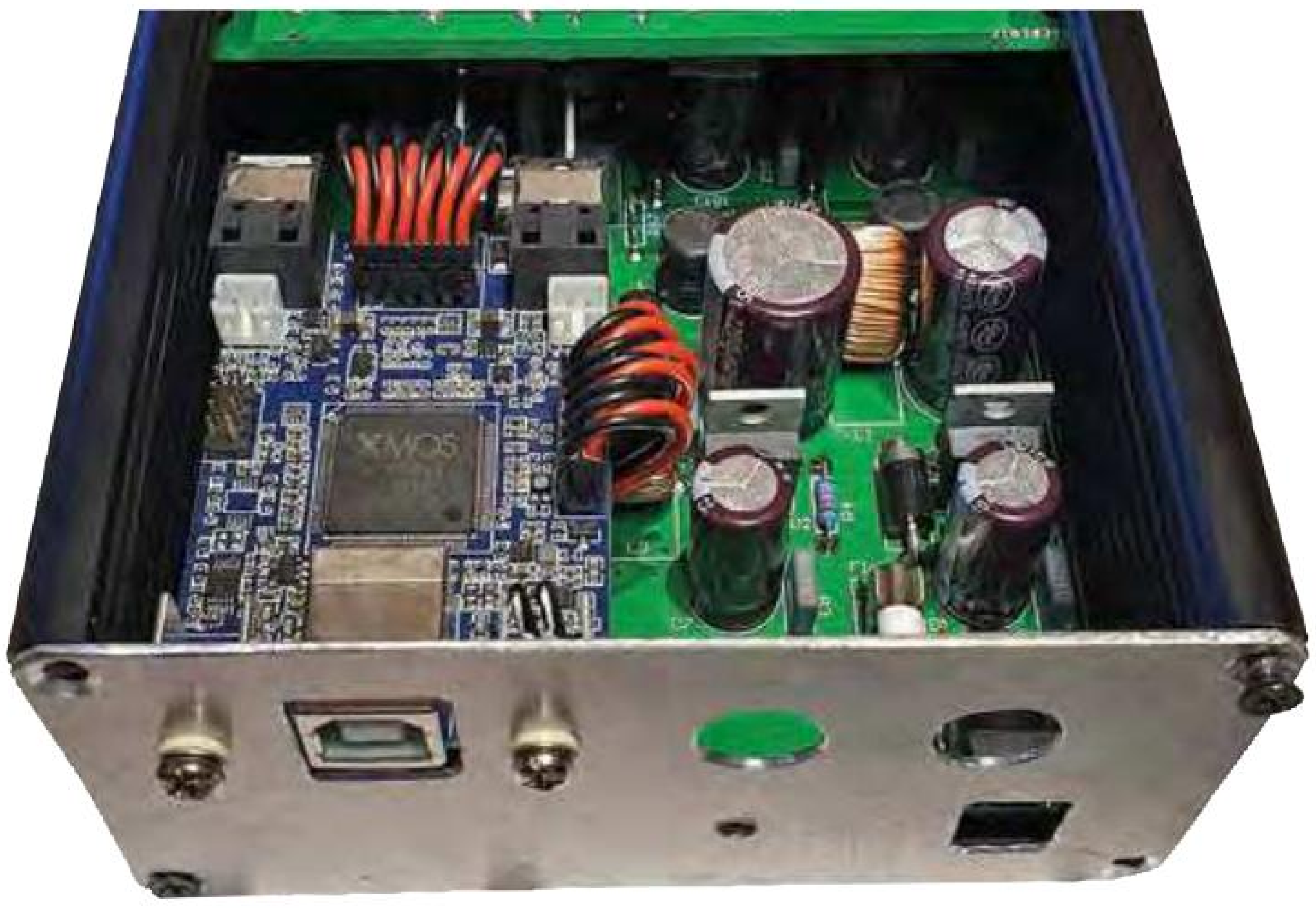


We need to solder the power cable to the main PCB as shown. Try to hook the wires around the resistor leads and keep things tidy!

The plugs with attached leads should have come with the MCHStreamer unit. To prepare them, measure and cut the pigtail wires to 50mm (5cm), as shown in the photo.



The MCHStreamer is supplied with pre-wired headers. Trim the leads to 50mm as shown. We need to keep these as short as practicable.

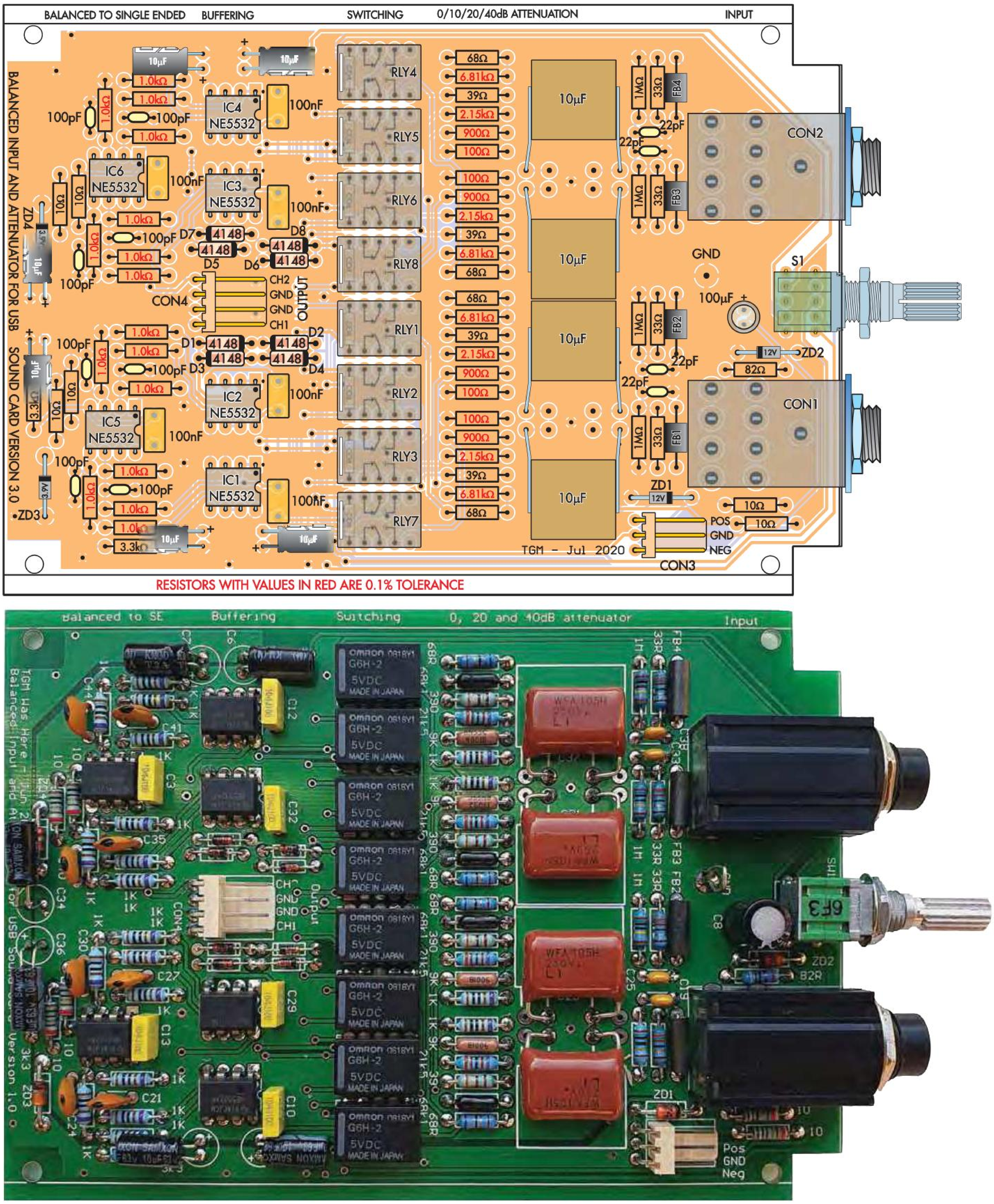


When plugged into the headers, the MCHStreamer ought to sit as shown above. A tight fit but without stressing parts.

Cut all the attached wires to this length and strip, twist and neatly tin 5mm at the ends. Note that while the plugs supplied have black wires on one side and red on the other, they will plug in either way around, and while there is a ground pin on one side, most of the pins carry signals. So it isn't critical which way around you solder them.

The best approach to soldering these to the sets of twelve pads on the PCB is to stand the connector vertically and looking from above, solder the inside row of wires to the outside row of holes in the PCB. We will be plugging this to the top of the MCH Streamer, which will swap the inside and outside rows of wires, as shown in the following photos.

With the two cables soldered in place, present the MCH-Streamer to the pigtailed headers and fold them as shown in the photo. The result is somewhat tight, but does fit inside the box.



BALANCED TO SINGLE ENDED
BUFFERING
SWITCHING
0/10/20/40dB ATTENUATION
INPUT
BALANCED INPUT AND ATTENUATOR FOR USB SOUND CARD VERSION 3.0
IC1 NE5532
IC2 NE5532
IC3 NE5532
IC4 NE5532
IC5 NE5532
IC6 NE5532
RLY1
RLY2
RLY3
RLY4
RLY5
RLY6
RLY7
RLY8
CON1
CON2
CON3
CON4
CH2
GND
GND
CH1
OUTPUT
S1
GND
ZD1
ZD2
ZD3
ZD4
D1
D2
D3
D4
D5
D6
D7
D8
FB1
FB2
FB3
FB4
POS
GND
NEG
TGM – Jul 2020
RESISTORS WITH VALUES IN RED ARE 0.1% TOLERANCE
Balanced to SE
Buffering
Switching
0, 20 and 40dB attenuator
Input

Fig.9: use this PCB overlay diagram and the photo below as a guide during construction, to see where the components are mounted on the board.

Watch the orientations of IC1-IC6, RLY1-RLY8 and all the electrolytic capacitors and diodes. The other parts either only go in one way, or it doesn't matter. Make sure to trim all soldered leads close to the underside of the PCB to prevent them shorting against the case later.

You may notice that diodes D5-D8 are missing from this photo – they were left off the prototype to verify that they had no effect on performance (they didn't!) but were added later. Constructors should fit all eight diodes (D1-D8) as shown on the component overlay above.

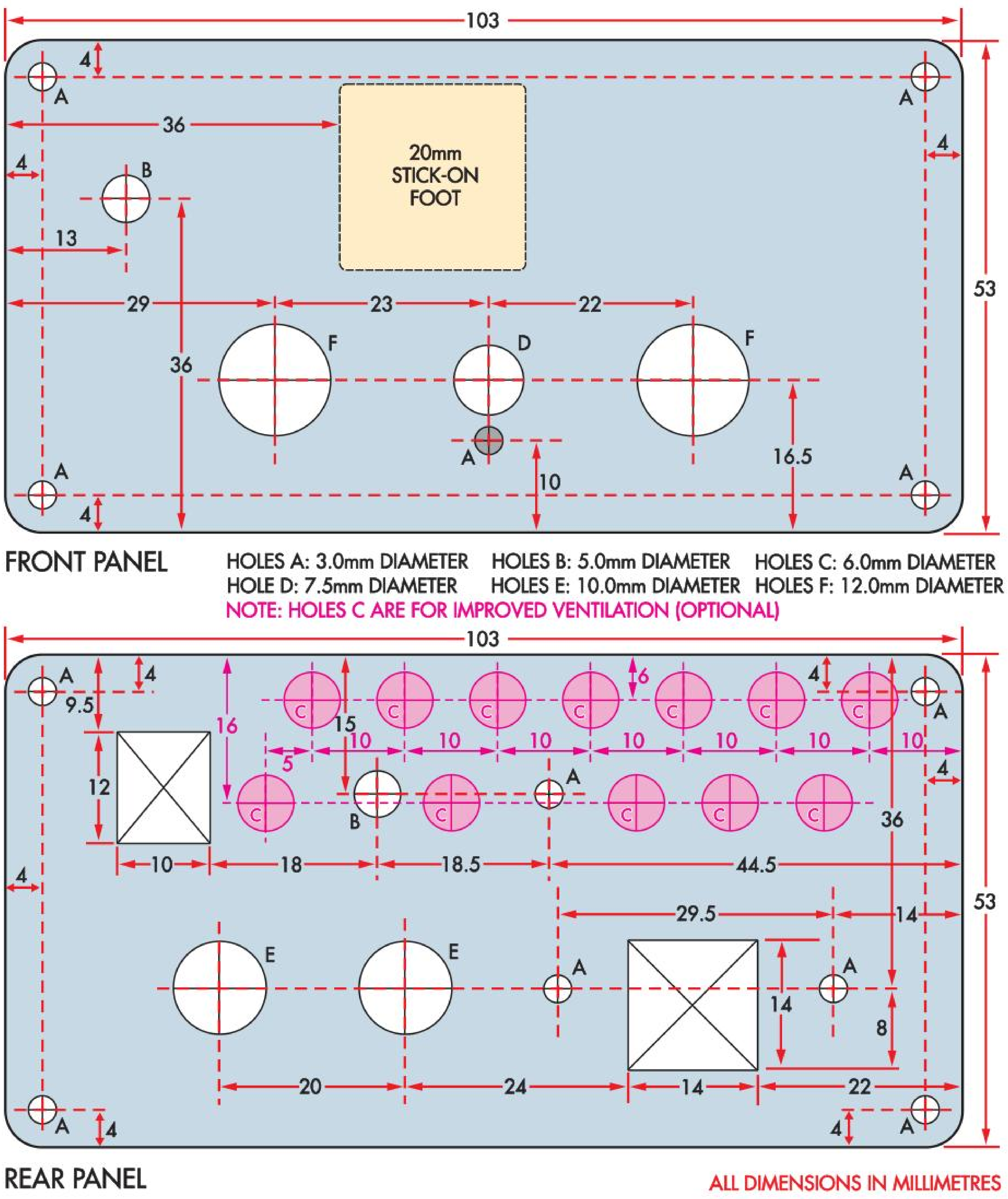

103
20mm STICK-ON FOOT
A
B
D
F
53
FRONT PANEL
HOLES A: 3.0mm DIAMETER HOLES B: 5.0mm DIAMETER HOLES C: 6.0mm DIAMETER
HOLE D: 7.5mm DIAMETER HOLES E: 10.0mm DIAMETER HOLES F: 12.0mm DIAMETER
NOTE: HOLES C ARE FOR IMPROVED VENTILATION (OPTIONAL)
C
E
REAR PANEL
ALL DIMENSIONS IN MILLIMETRES

Fig.10: this shows the sizes and shape of the front and rear panels (front panel at the bottom), and where to cut or drill holes in them. The 3mm hole below the 7.5mm hole only needs to go partway through the inside of the panel. The ventilation holes shown in red are optional, but do help to keep the internal components at a reasonable temperature in hotter environments, so are recommended. (You can download this diagram from the January 2022 page of the *PE* website.)

At this stage, it's worth checking both PCBs to make sure that you trimmed all component leads neatly. If you've left any long, they could interfere with, and possibly short out against the case once inserted into it. There is adequate room below the *USB Sound Card* to accommodate normal lead lengths; you should not have any problems provided you are tidy.

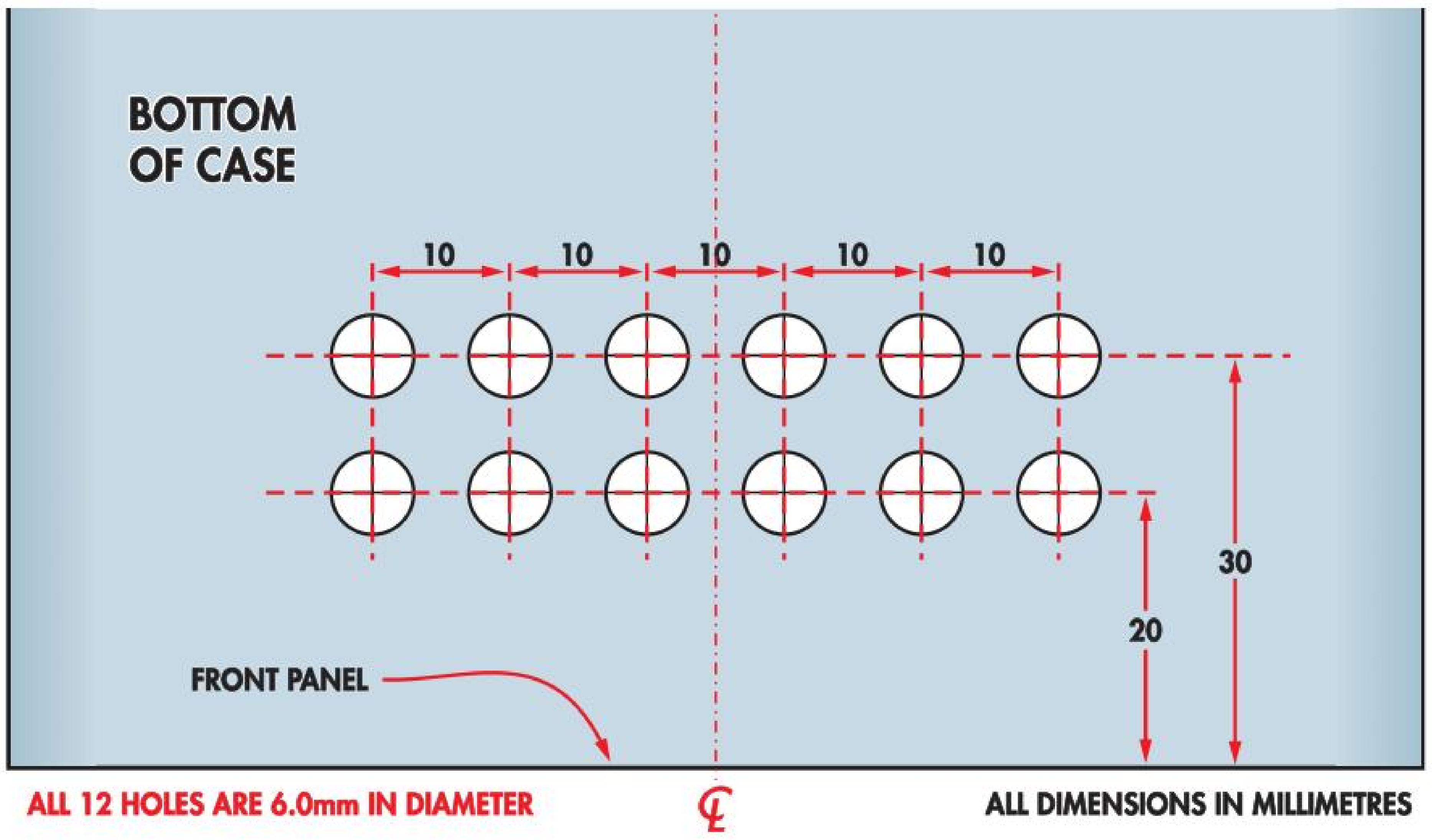

BOTTOM OF CASE
10
30
20
FRONT PANEL
ALL 12 HOLES ARE 6.0mm IN DIAMETER
ALL DIMENSIONS IN MILLIMETRES

Fig.11: if you drilled the ventilation holes on the rear panel, you should also drill some holes towards the front of the bottom panel, as shown here. These allow cool air to be drawn in via convection, which flows along and cools the two boards before exiting through the holes at the top of the rear panel.

Testing

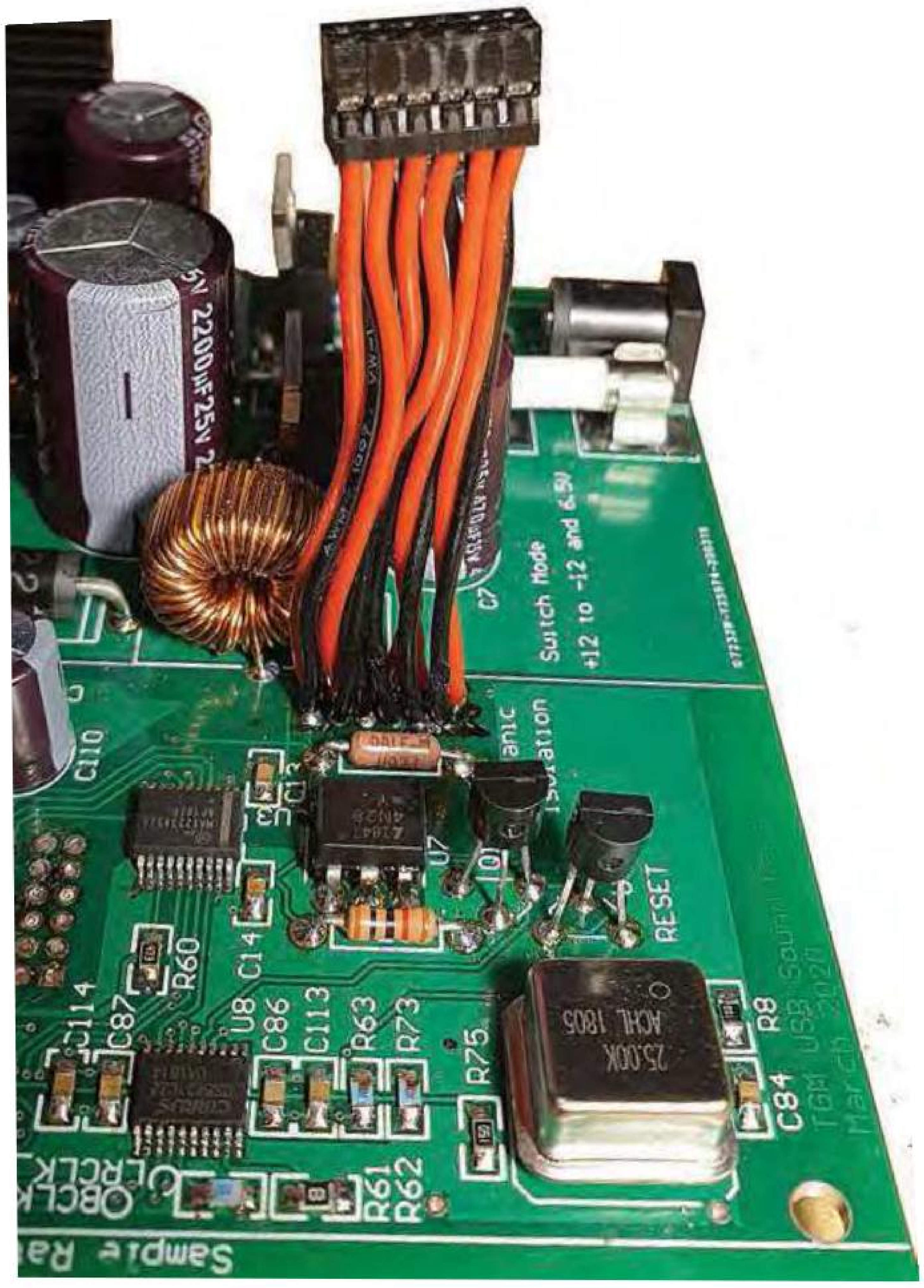
Before inserting everything in the case, it's a good idea to make sure it's all working. If you haven't already tested the *USB SuperCodec* board in isolation, do it per the instructions in the third *SuperCodec* article. This will also involve installing the MCHStreamer drivers and getting it working on your computer.

Power down the *SuperCodec* board and plug the power connector from the *SuperCodec* PCB into the three-pin header on the *Balanced Input Attenuator* board (CON3). Then use the length of shielded cable with plugs on either end you prepared earlier to connect the audio output of the *Attenuator* (CON4) to the audio input on the *USB Sound Card* (also CON4).

For the outputs, make up a twin shielded cable with RCA chassis connectors on one end and a 4-pin polarised plug on the other, as per the final *SuperCodec* article (if you haven't already). Plug this into CON5. Make sure the whole rig is resting on a non-conductive surface, and nothing can short to anything else before proceeding.

Now would be a good time to check, using a continuity tester, that the +9V and –9V rails on the two boards are connected the right way around and not swapped. Check for 0V continuity between the boards at the same time. Then, with the MCHStreamer plugged into the *USB Sound Card*, plug in the 12V supply to power the whole assembly up.

Assuming it passes the 'smoke test', verify that all the supply rail voltages are still correct. You would have tested these with the *SuperCodec* alone already, but a fault on the *Balanced Input*



When soldering the MCHStreamer connector to the board, the red and black rows of wires need to cross over as shown.

The MCHStreamer is fixed to the rear panel using an insulating bush kit. Don't forget this!

Assembly is tight, but with the cable lengths recommended it allows the *Balanced Attenuator* to slide out enough to allow the output and power connectors to be plugged in. Watch for the cables snagging on parts on the *SuperCodec* main board though.

Attenuator board could cause them to be wrong now. Assuming they're OK, check that the attenuator relays work; each time switch S1 is moved, it should generate a nice click from the relays.

Then plug the whole device into your computer and repeat the output test that you carried out earlier. Check that the *USB Sound Card* generates a signal when you play sound or music. If this does not work, check that there are no faults on the *Balanced Input Attenuator* board and check the wiring thoroughly. We have not changed this part of the *USB Sound Card*, so it should still work fine.

Now launch your recording or analysis software (Audacity will work for basic testing). Set the input attenuator to 0dB, apply an audio signal of no more than 1V RMS to one of the balanced inputs (eg, using a test oscillator) and check that it is received undistorted in the correct channel (left or right).

If you don't have a test oscillator, you can rig up some cables to loop the *USB Sound Card's* outputs back to the balanced inputs and play a test tone. If you do this, remember to set the output level no higher than –8dB to avoid overloading the inputs.

If that checks out, switch to the –10dB setting and verify that the input level drops appropriately. If your test oscillator level can go higher, increase it to a maximum of 3V RMS and confirm that you get undistorted near-full-scale input signals. You can also check the –20dB and –40dB settings and verify that the input level drops appropriately, but the waveform shape remains undistorted.

A view with the bottom panel off during assembly. Next comes the *Balanced Attenuator* and base plate.

Drilling the front and rear panels

As mentioned earlier, we are using the same case that was used for the basic *USB Sound Card*. However, because we've had to pack an extra board in, the boards mount to the front and rear panels differently. The revised drilling details are in Fig.10.

You can copy/print this and use it as a template, or you can measure with a ruler and mark out the hole locations on the panels.

If you have already drilled the panels for the basic *USB Sound Card*, it is not hard to cut and make new panels from an aluminium sheet of a suitable thickness. You can achieve a high-quality finish by sanding with 400 grit paper after making the holes, then spraying the panels with satin finish black paint.

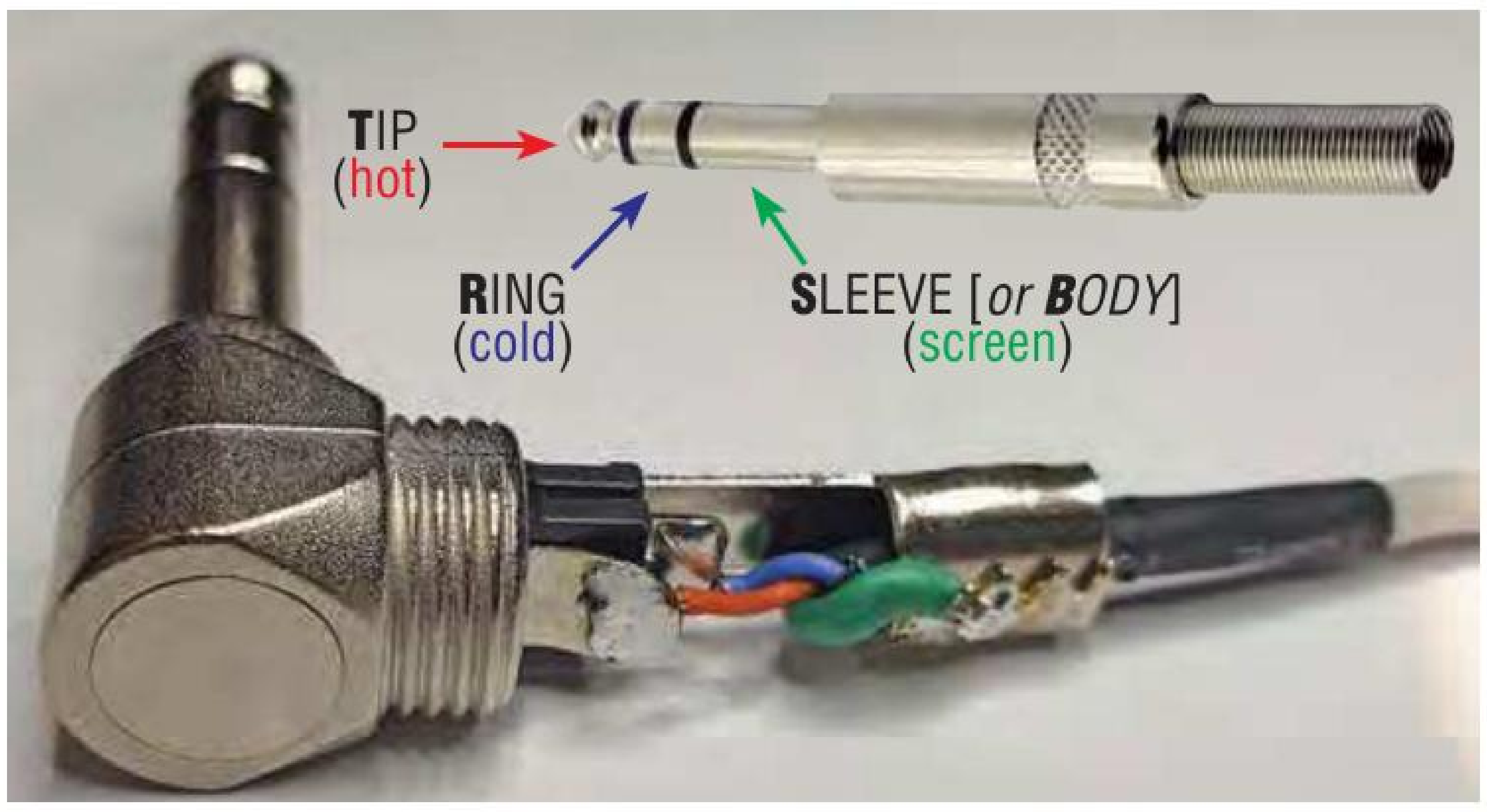
Cut and finish the metal panels as shown in Fig.10. The 3mm 'hole' below the switch hole on the front panel (7.5mm in diameter) does not need to be drilled through; it is there to hold the locking pin on the switch.

Note the series of holes on the rear panel shown in red; these are for venting hot air and help to lower the operating temperature of the internal components by around 5°C. These are necessary due to the extra internal dissipation due to the *Balanced Input Attenuator* board.

You could opt not to drill these if you are never going to operate the device at higher ambient temperatures (ie, if it will always be used in an air-conditioned room). But as they are on the rear panel, they are unobtrusive, and it's generally better to keep the components as cool as possible.

Similarly, we have prepared a bottom panel drilling diagram (Fig.11) which shows the location of some extra holes in that panel. Combined with the holes on the rear panel, these

First extend the 'hot, 'cold' and screen of the leads, then cover with two layers of heat-shrink to make a robust test lead.



Connnections to the 6.35mm stereo plug – we have used the ‘TRS’ naming standard, although you will often see ‘TRB’ used instead. It doesn’t matter: the sleeve IS the body!

provide some convective cooling to drop that temperature. If you’re going to drill one set of holes, you should drill both, or they will not be effective.

When finished, install the rubber foot on the front panel as shown in Fig.10 to ensure that the USB Sound Card is held snug against the rear panel. We cut the chamfer off the top of the foot to ensure that the rubber foot fully pushes the PCB back into the case. Then do a test assembly and make sure everything fits OK. Get used to the jiggling required to get things in.

Final assembly

Assembly is pretty straightforward. Slip the bottom panel off the case, and slide the *USB Sound Card* in the top slot with the components facing to the bottom panel. The MCHStreamer should already be plugged to the *USB Sound Card*.

Attach the MCHStreamer to the rear panel using an M3 crinkle/star washer, TO-220 bush and fibre or plastic washer. The bush and insulating washer are to ensure that it is insulated from the rear panel, as described in the *USB Sound Card* article. Make sure the bezel is in place (omitted in photo). You can now put the four screws into the rear panel.

Then mount the output connectors as described in the *USB Sound Card* article. Again, make sure they are insulated from the case.

Attach the earth screw and solder tags as described in the *USB Sound Card* article, and solder the 10nF capacitor between the Earth tag and ground of the output connector.

Plug the 18cm cable that goes between the *USB Sound Card* input and *Balanced Attenuator* output into CON4 on the *SuperCodec* board. Now slot the *Balanced Attenuator* into the bottom slot, with its components facing towards the USB Sound Card.

As you slide it in, pull out the power cable and audio cable that run between the cards and plug them into the *Balanced Input Attenuator* power connector and output connector. You will need to jiggle things to make sure that the cables do not foul between the two boards. Trust us; it will fit!

Modifying your prebuilt SuperCodec

If you already built the *SuperCodec USB Sound Card* and have soldered the headers to the back of the PCB, it is possible to still add the *Balanced Input Attenuator*, but it’s tricky. Removing the two through-hole headers is not as simple as it sounds. We did it on our prototype, but note that this procedure is for advanced builders wishing for a little excitement!

You will need a hot air gun set to about 290°C, a pair of pliers and a steady hand.

Set the *USB Sound Card* on edge and grip the first 12-pin header with the pliers. Heat the solder side of this connector with the air gun, from a distance of about 10mm, and gently wriggle the connector with the pliers. Observe the solder connections and adjust your heating until you see some, then all pins moving in the PCB.

At this point, gently pull the connector out while continuing to heat, ensuring that all pins are free to come out. Do not use force!

Then use a solder sucker to clean the holes up, ready for the MCHStreamer connector wires.

Ensuring that the rubber foot is stuck to the front panel as shown in the drawing (Fig.10), push the front panel bezel into place. You then need to slide the bottom panel on. After that, push the 6.35mm sockets and switch through the front panel and screw these tight with the provided mounting kits. You can now put the four screws into the front panel. At this point, you should be ready to go!

Making some test leads

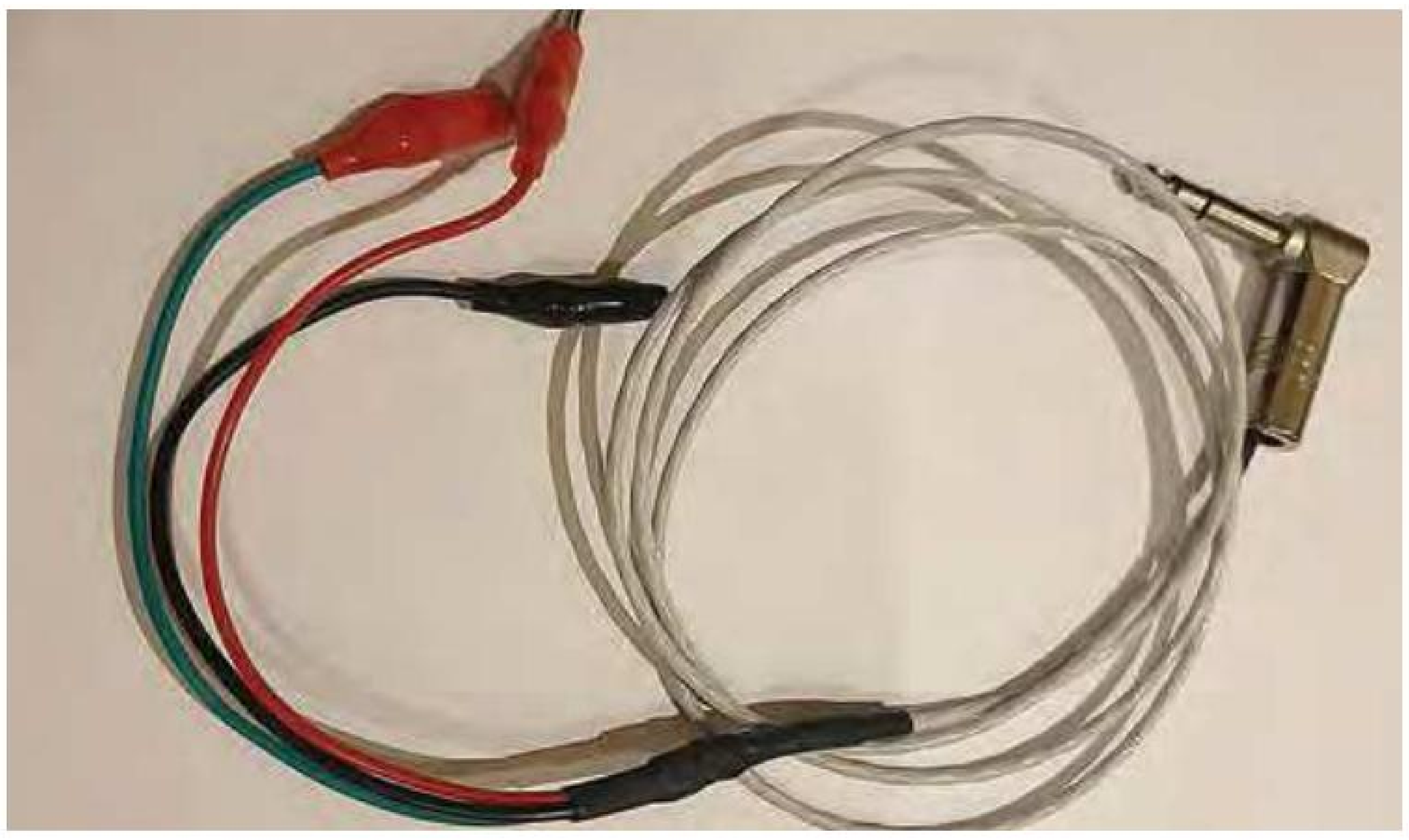
If you’re primarily building the *Balanced Input Attenuator* so that you can make recordings from equipment with balanced outputs, chances are you already have suitable cables. You may need to purchase (or make) some XLR to TRS adaptor cables, to allow you to plug XLR equipment into the inputs. These are readily available and usually not too expensive; for example, Altronics Cat P0750.

For audio equipment and distortion testing, though, you will probably want a set of cables with alligator clips on one end and TRS jacks on the other. This provides you with maximum flexibility to connect to the ends of various components in audio gear, as needed.

The process of building leads is open to your needs and imagination. We will show our approach, but this is by no means the only way.

We used 90° ‘stereo’ TRS 6.35mm jacks to get the cables out of the way of the attenuation switch. Strip 25mm off the ends of the balanced (twin-core shielded) cable. Also, strip 10mm off each of the inner conductors. Strip 10mm off each end of short lengths of red, green and black hookup wires, and twist and solder these to the balanced cable as shown. Then slip a 20mm length of 3mm heatshrink over the solder joints and shrink them down.

Put heatshrink over the alligator clip to cable transition to act as strain relief, then slide the rubber boot over the lead.



Our finished lead – when constructing the prototype we ran out of green clip covers – at least the lead is green!

Test programs for your PC

We have used AudioTester 3.0 for testing a lot of different audio gear. This is available as shareware, and a paid subscription is available. It is good but not perfect. You need to select the ASIO interface for playback and record, and also 192kHz for the sampling rate. You can download it from here: **www.audiotester.de/download.htm**

One problem we've noted with AudioTester is that its THD+N readings seem off, especially with test signals well below or above 1kHz. We prefer to use it to measure THD only, and SNR only, then compute the THD+N reading as the RMS sum of the two figures.

It appears to do a good job of computing THD, but you need to be careful to use a test signal that isn't too far below the maximum that the device can accommodate. Otherwise, the resulting harmonics can be so low that they are unmeasurable or severely quantised, and you get an artificially low distortion reading.

One alternative that we have used, but not as much, is ARTA. Many people seem to like this software. You can get it from **www.artalabs.hr**

Now take two 40mm lengths of 6-8mm-diameter heatshrink tubing and shrink these over the junction of the cables. We used thin cable; you may need to use larger diameter heatshrink here. Then take two 60mm lengths of tubing and put these over the top as a strain relief. This will give you a secure connection and minimise the likelihood of wire fatigue.

The next step is to connect alligator clips of your preference to the red, black and green wires. Start by slipping the rubber covers over the wires first, so you don't forget them! Then slip a 15mm length of 3mm heatshrink over the cable.

Strip off an appropriate length of insulation; for the Jaycar clips, this is about 6mm. Solder and trim off any daggy bits, then crimp the metal strain-relief tabs, right at the end of the clip, over the wire.

For extra protection, slip the heatshrink down the wire and over the metal strain relief and shrink. Slide the covers over the clips, and these are done!

The 6.35mm jacks are similar, just much larger. Don't forget to slip the covers onto the cable first! Follow with 30mm of 3mm diameter heatshrink as a final cover for the cable (we used thin cable, you may need to use larger diameter tubing).

We stripped about 15mm of insulation off the cable, and applied about 8mm of 2mm heatshrink to the earth screen.

Check the connections for the solder lugs to the tip, ring and sleeve. The tip is 'hot' (red), the ring is 'cold' (black) and the sleeve is ground (green).

Solder these on. If you intend to use this for testing amplifiers, the connector and cable will see the full amplifier output voltage in some cases. Make sure that all connections are secure and that clearances of no less than 1mm are present and secure. Do not use these on mains voltage, in any circumstances!

Final testing

With the case all put together, power the unit back up, plug it back into your computer and verify that everything still works as before. If it doesn't, you may have a short circuit somewhere, or forgot to plug something back in when you put it all in the case.

If you are recording from a professional audio source, plug this in and set the attenuator level to 10dB, and you are all set.

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Teach-In 9 – Get Testing!

This series of articles provides a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. It provides hints and tips on using, and – just as importantly – interpreting the results that you get. The series deals with familiar test gear as well as equipment designed for more specialised applications.

The articles have been designed to have the broadest possible appeal and are applicable to all branches of electronics. The series crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone!

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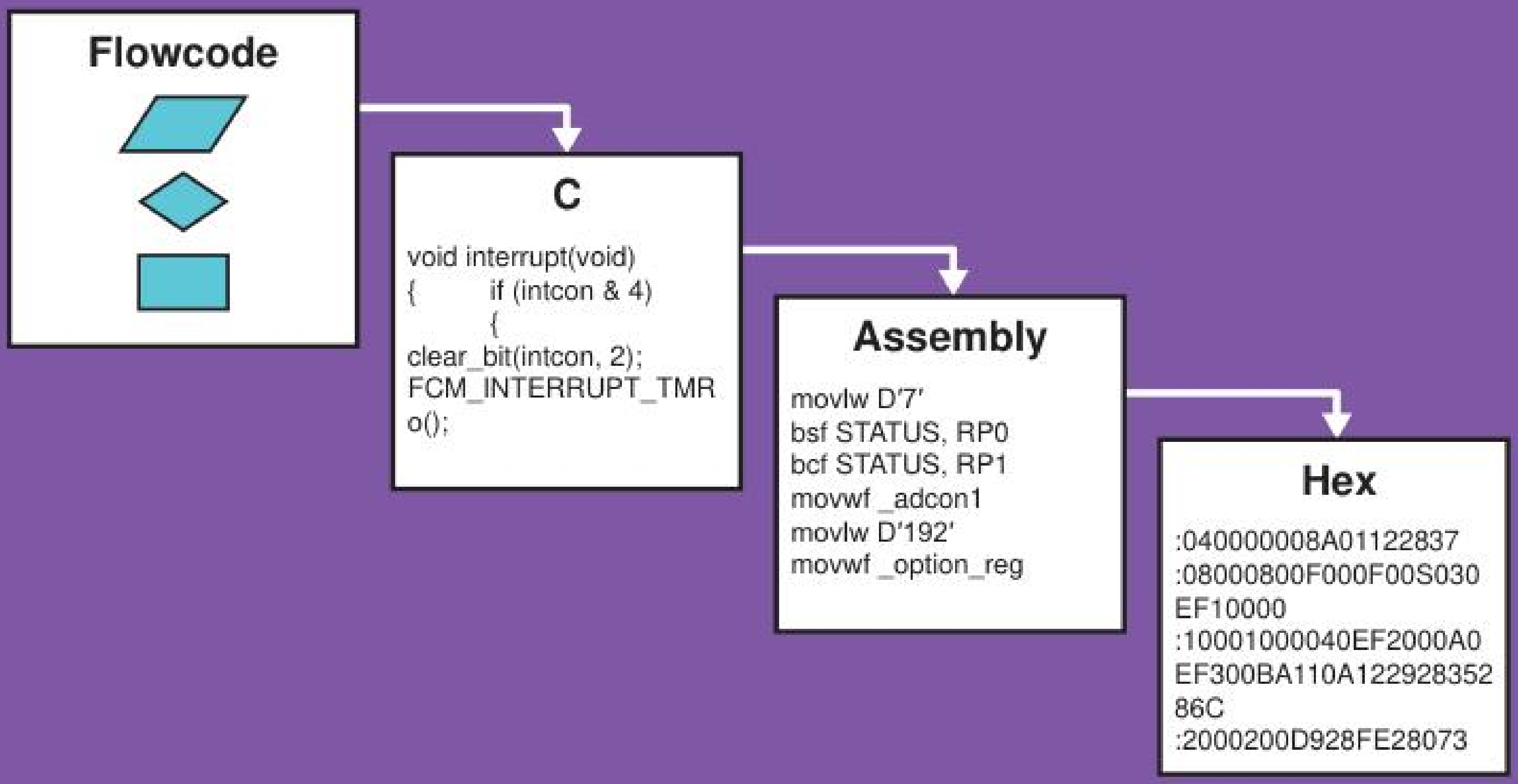
Flowcode
Graphical Programming



```
void interrupt(void)
{       if (intcon & 4)
        {
clear_bit(intcon, 2);
FCM_INTERRUPT_TMR
o();
```

```
movlw D'7'
bsf STATUS, RP0
bcf STATUS, RP1
movwf _adcon1
movlw D'192'
movwf _option_reg
```

```
:040000008A01122837
:08000800F000F00S030
EF10000
:10001000040EF2000A0
EF300BA110A122928352
86C
:2000200D928FE28073
```

Programming with Flowcode: RedBoard and PICs – Part 1

In the September 2021 issue of *PE*, I introduced you to Flowcode, an integrated development environment (IDE) for programming microcontrollers such as Arduino, Raspberry Pi, many 8, 16 and 32-bit PICs and ARM devices. It achieves this by using flowcharts instead of text-based languages, which has the double benefit of making programming simpler and faster.

Flowcode contains hundreds of pre-made component libraries, allowing users to interface with a host of sensors, inputs, outputs, displays and electromechanical devices. Despite its simplicity and ease of use, Flowcode is a powerful tool, allowing users to develop even the most complex of embedded systems.

Flowcode supports both third-party hardware (including PICs, Arduinos, ESP32, ARM and Raspberry Pi) and also its own Matrix products. This powerful design tool is compatible with a huge number of 'targets' (the device being programmed). To get an idea of how many there are, just take a look here: **https://flowcode.co.uk/embedded/targets/**

Although modern devices are supported – eg, the PIC16(L)F15325 – in this series I have deliberately chosen a couple of popular older devices:

1. SparkFun RedBoard (an Arduino Uno clone) – USB powered
2. A PIC, the 16F88 I/P – needs a 5V external supply.

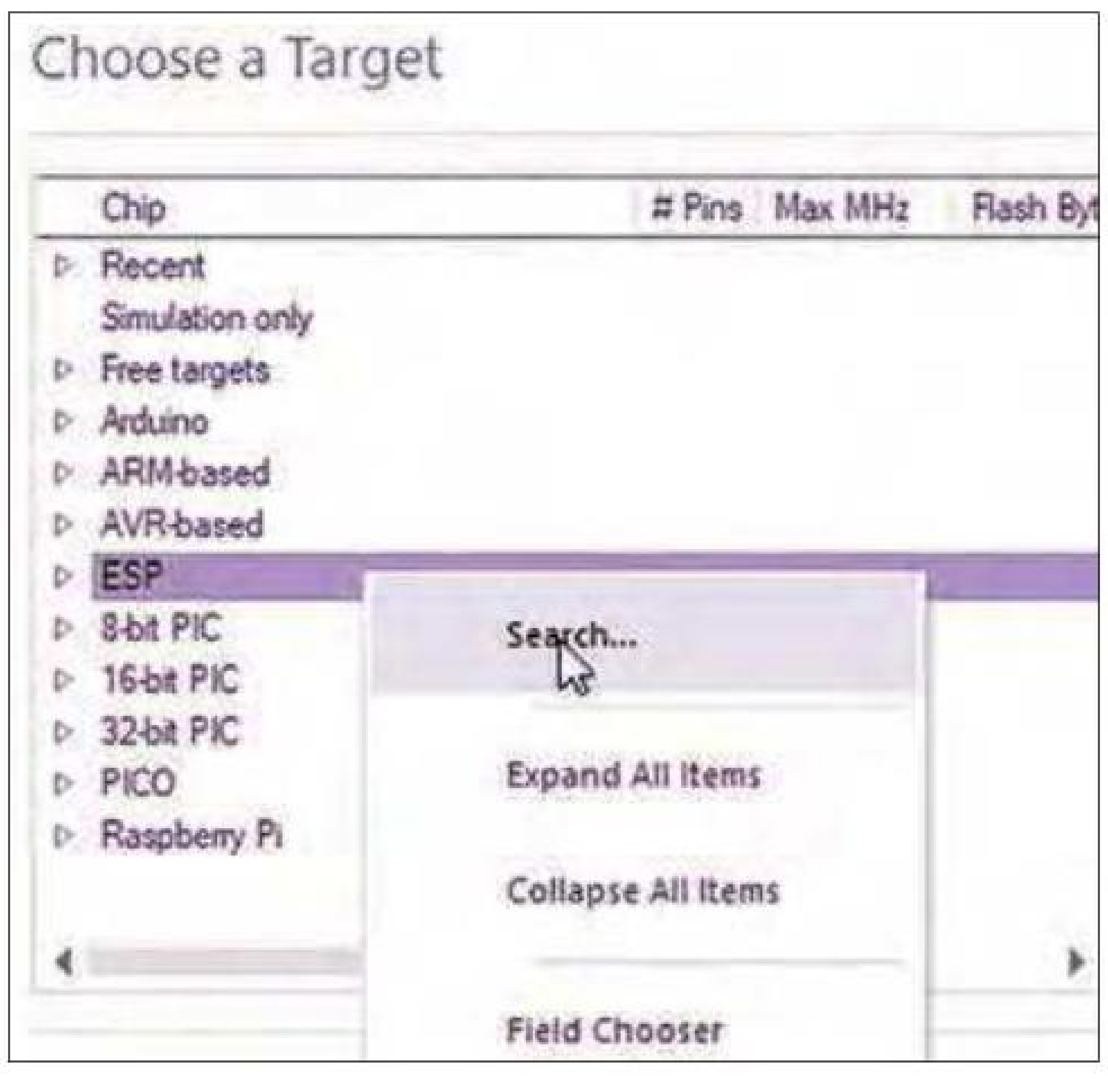


Fig.1. Using the Search function to find the target device.

The great advantage of these two is that they are part of Flowcode's time-unlimited free-to-use package. This means you can follow along at your own pace without worrying that you are limited with a 30-day trial. (See the box at the end for details on using Flowcode for free.)

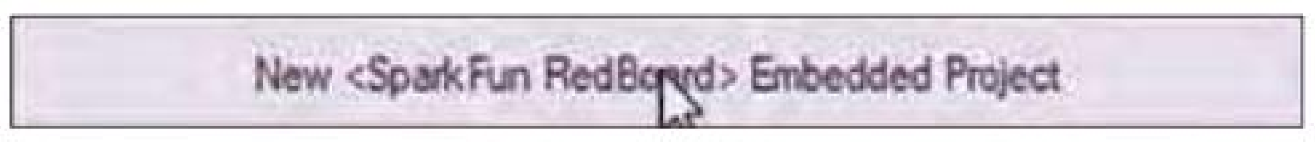
Building our first RedBoard project

In our first project we will provide an overview of the Flowcode IDE and use it as a vehicle to demonstrate how users interact with the environment and add components to the simulation panel. To do this we are going to create a traffic light flowchart, make sure it *simulates* correctly and then build the traffic light with real hardware. Finally, we will compile the flowchart to the microcontroller and watch it operate on the hardware. We will go into quite a lot of detail about using the software to set you up for more advanced projects later in the series.

Let's start by looking at what we'll need. First and foremost, you will of course need a Windows-based PC with a copy of Flowcode 9 installed. The hardware for our RedBoard project is simple:

- Red, orange/yellow and green LED – one of each, use cheap 5mm devices
- 330Ω current-limiting resistors, 3 off – any 0.25W type will do
- Solderless breadboard
- SparkFun RedBoard (DEV-13975) or Arduino Uno
- Male-to-male jumper wires, 5 to 8 off, depending on what target device is used
- Tactile switch, suitable for mounting on the breadboard (push-to-make type)
- USB cable to both power and program the RedBoard/Arduino Uno.

What about programming a PIC? – we will come to that later, but if PICs are your favoured destination, then you will also need to invest in a PIC programmer. We recommend the PICKit 4, but if you know your way around the PICkit 3 or other PIC programmers then they should be fine too.



New <SparkFun RedBoard> Embedded Project

Fig.3. Selection of a new target project.

Our first task is to download and install Flowcode V9 plus the correct Toolchains (compilers, rules and useful target-specific files for working with the 'AVR/Arduino' and '8-bit PIC') from Matrix TSL at: **www.flowcode.co.uk/download**

Before we proceed, it's well worth knowing that you can find out much more about specific Flowcode items at the Flowcode Wiki: **www.flowcode.co.uk/wiki**

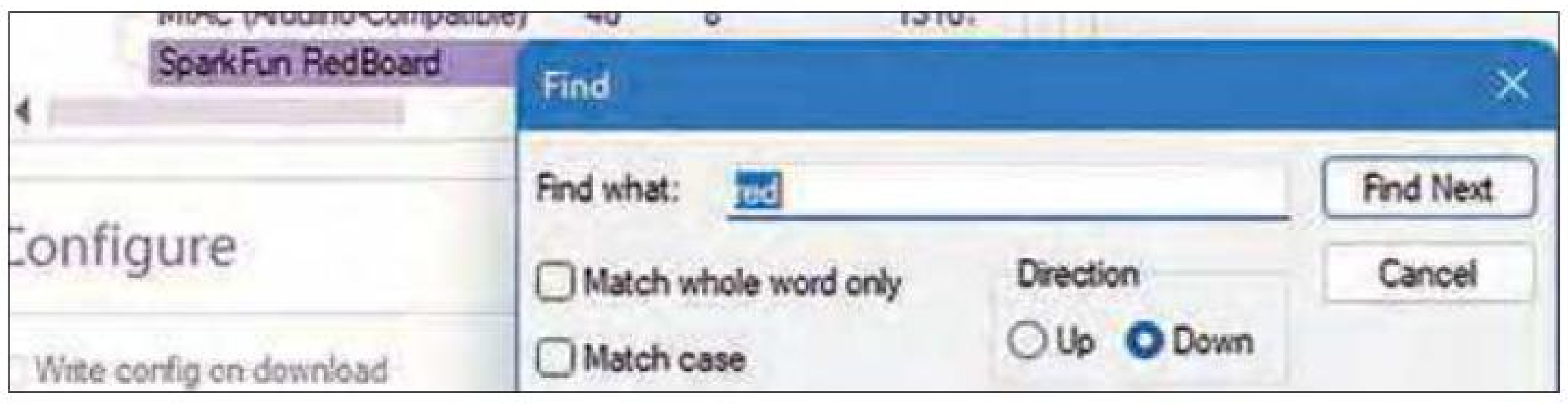
First steps

Once Flowcode and the Toolchains are installed, run Flowcode and select 'Library Updates'. In the Updates pop-up window, select 'Download'. When all updates have been downloaded, click 'OK' and then 'Exit'. Next, select 'New Project'. To select our target device, right-click on any target below the 'Choose a Target' tab. Fig.1 shows you can use a built-in search option. Select search and use 'Find' to enter the partial name of the required target – we type 'red', and click 'Find Next' to bring up the RedBoard (see Fig.2).

At the top of the New Project tab, you should see the new target device to select, as shown in Fig.3. Click on this option and save your project from: File > Save As. You will need to name the project since this is the first time of saving – I saved/named mine as 'LED Traffic Light'.

One-second flasher

Before starting any project, you will save a lot of time and headaches if you first create a basic one-second flasher. The purpose of this is to check the 'Project Options' match the hardware – in other words, the target's 'settings' are right. If they don't match, then you



Find what: red

☐ Match whole word only

☐ Match case

Fig.2. The Find Next option will bring up matching items – just entering 'red' for 'RedBoard' will work.

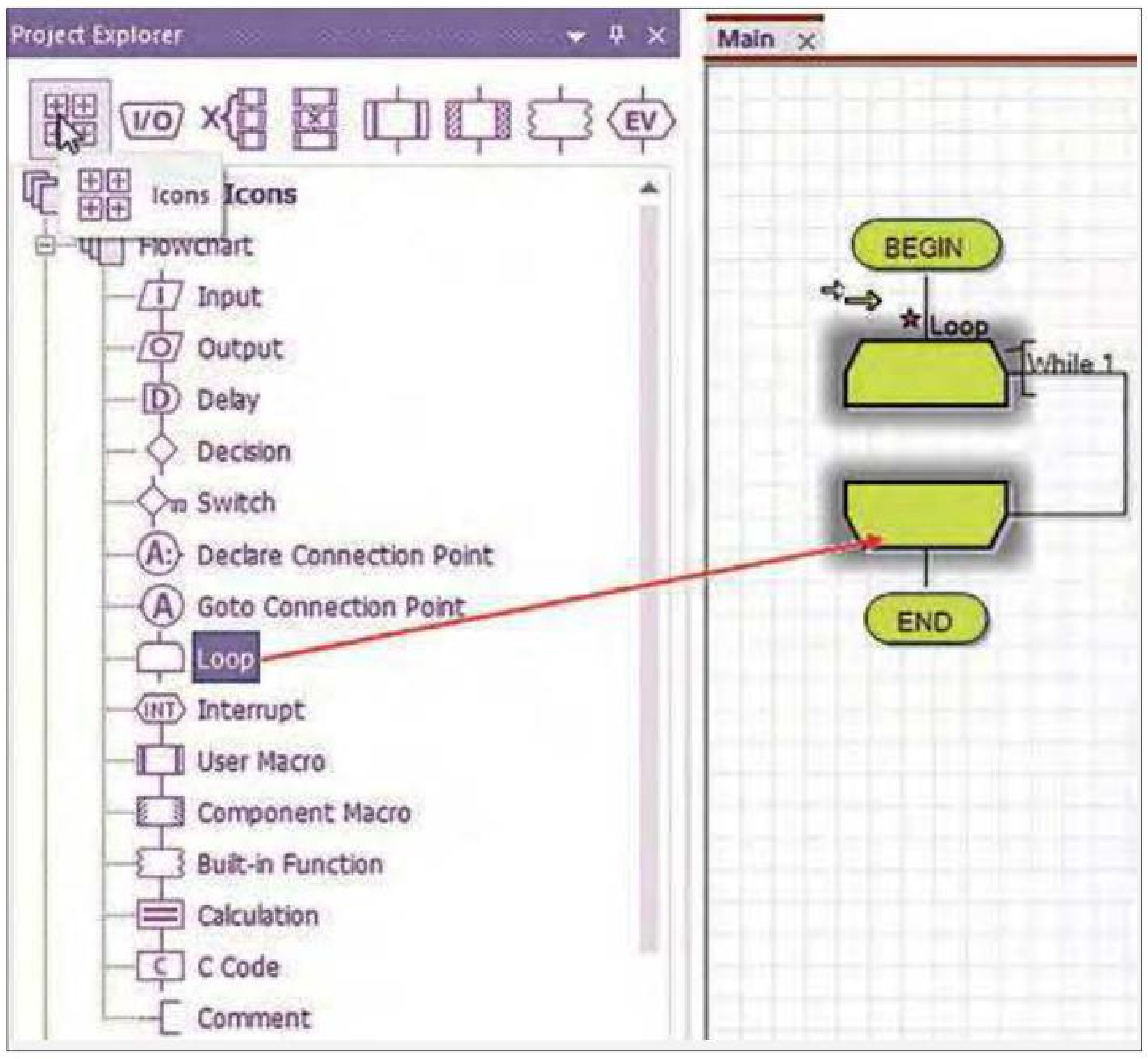

Project Explorer
Main
I/O
EV
Icons
Flowchart
Input
Output
Delay
Decision
Switch
Declare Connection Point
Goto Connection Point
Loop
Interrupt
User Macro
Component Macro
Built-in Function
Calculation
C Code
Comment
BEGIN
Loop
While 1
END

Fig.4. Dragging a continuous Loop to the flowchart.

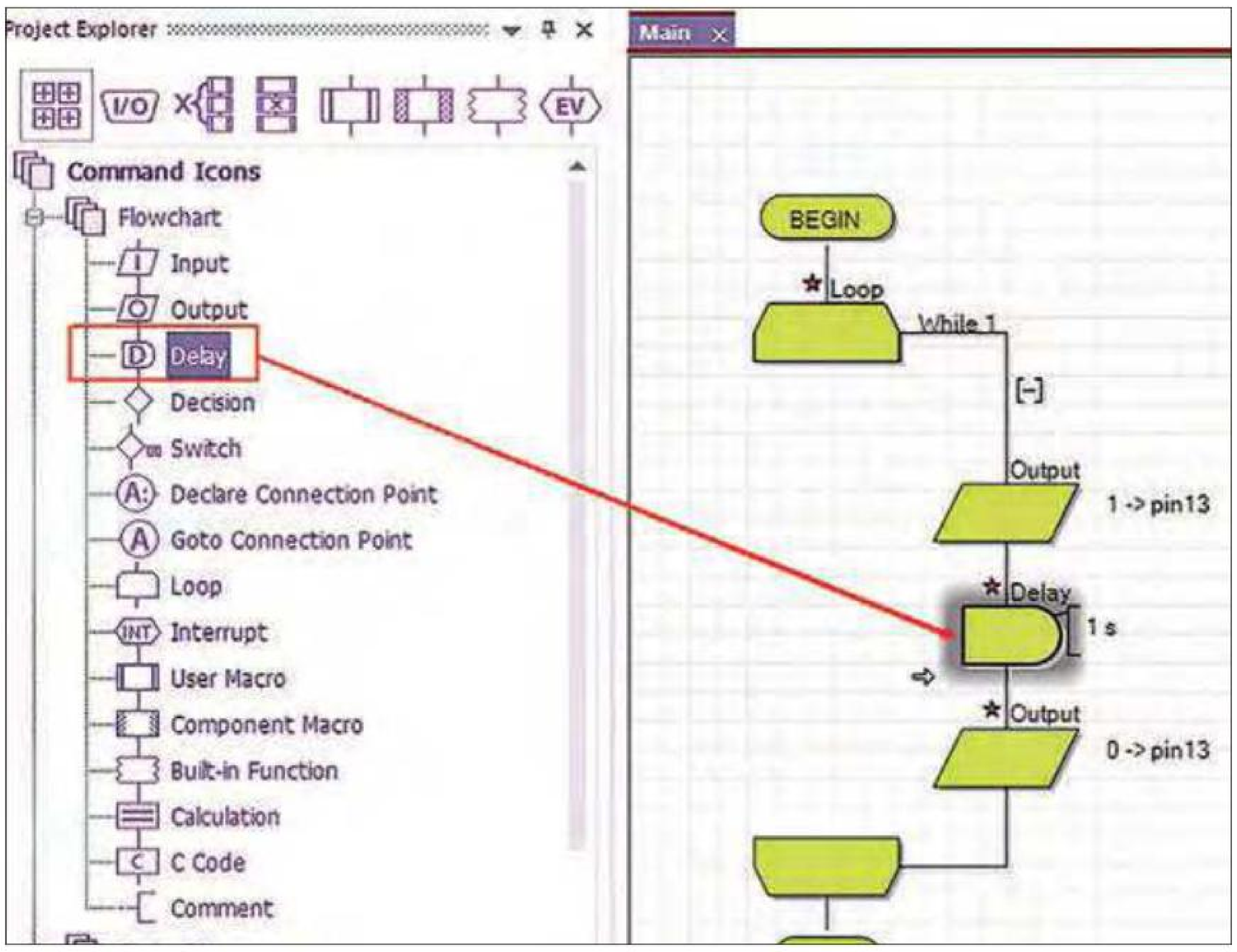

Project Explorer
Main
I/O
EV
Command Icons
Flowchart
Input
Output
Delay
Decision
Switch
Declare Connection Point
Goto Connection Point
Loop
Interrupt
User Macro
Component Macro
Built-in Function
Calculation
C Code
Comment
BEGIN
Loop
While 1
[-]
Output
1 -> pin13
Delay
1 s
Output
0 -> pin13

Fig.6. Dragging a Delay to the flowchart.

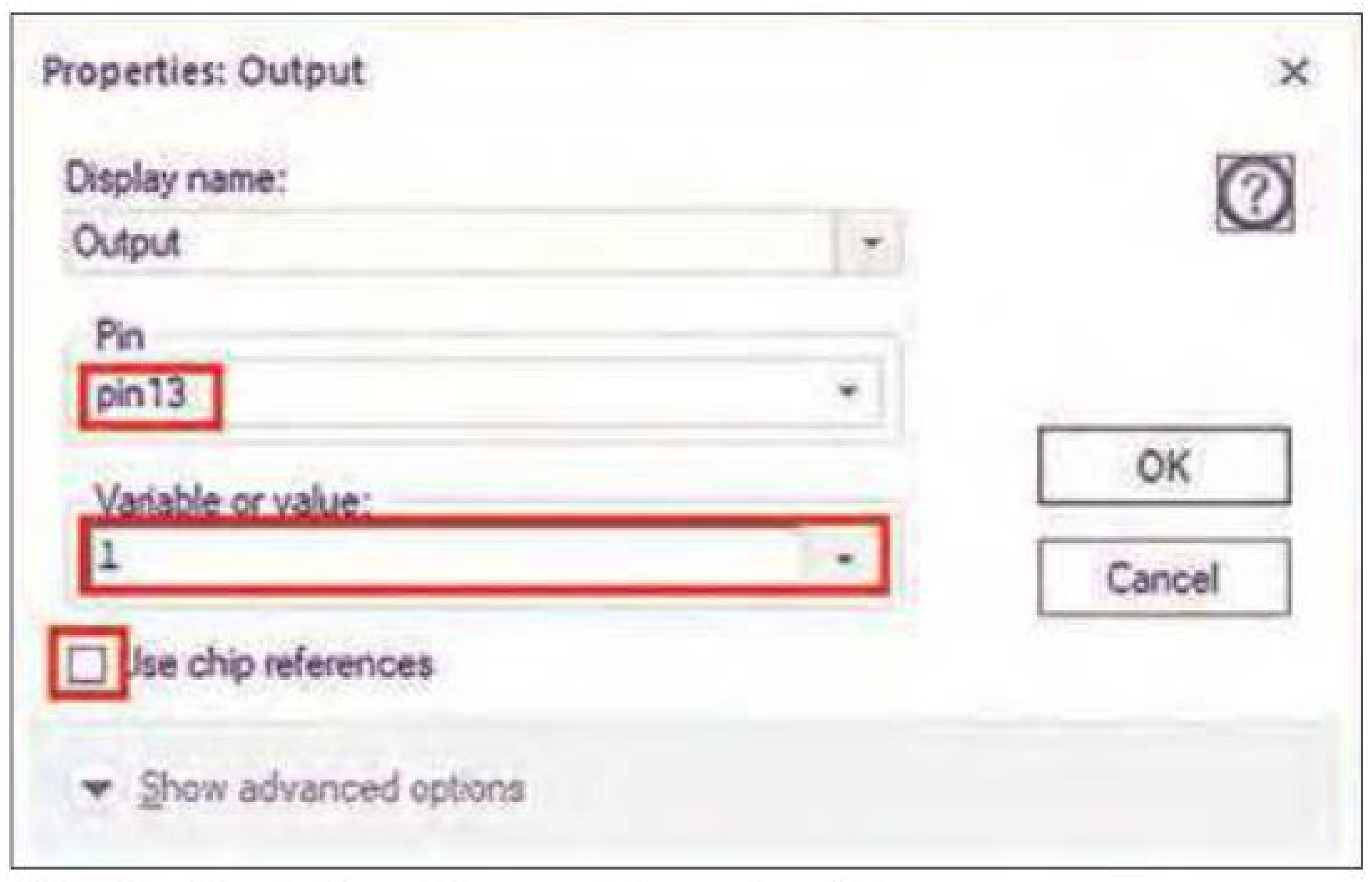
will never get your project to work and the LED will either remain on, off or flash at the wrong rate. By testing the Options on the simplest of projects (ie, a single-LED flasher) we can check important parameters without setting up a complicated program that is doomed to fail. We will run through this exercise for the RedBoard, even though the Project Options match hardware by default for this particular target. Do be aware that for other targets, especially PICs, you will need to make some choices manually.

First, go to 'Project Explorer' and add a Loop in our flowchart to make our microcontroller execute code indefinitely. (This loop condition means that whatever code is placed within our loop will execute forever.) We click and drag a Loop over to the flowchart, as shown in Fig.4.

By default, the loop command is set to be a `while(1)` Loop, so it does not need any further configuration. (Note: the red star next to 'Loop' in Fig.4 means your project has not been saved since the last modification. Do get into the habit of saving regularly, or better still, set up Autosave from: View ribbon > Global Settings > Application tab.)

Outputs

The next icon we will add (drag to the flowchart working area) is called an 'Output'. These are used to set the state of a target device's pins to high or low – hence the name, 'Output'. We set the output pin number choice in Properties, and the value can either be fixed in properties (high or low) or can be a variable, where the high/low value is determined by program operation.


Properties: Output

Display name: Output

Pin: pin13

Variable or value: 1

☐ Use chip references

Show advanced options

Fig.5. Set the Output to pin 13.

Next, we need to configure the Output. This is done by double-clicking its Icon to view its Properties. We will use the RedBoard's pin 13 to drive the LED that is built onto the RedBoard, and configure our Output's Properties to match this. To use pin 13 in this way, ensure the 'Use Chip References' box is unticked. If you leave it ticked then it will use the board's IC pin name instead; for example, `PORTB5`. (See Fig.5.)

Next, we want to turn the LED on, which is achieved by writing a value of `1` in the 'Variable or value' box. Of course, to make an LED flash, we must turn it on *and* off. Place another Output icon on your flowchart, below the first one, and configure it as before – except this time write a value of `0` to turn the LED off.

Adding Delays

Our final step is to add delays. Microcontrollers operate at very high speeds (a 16MHz crystal is used on the RedBoard as standard). The default 16MHz crystal makes the PIC operate at four million instructions per second. If it were to turn the LED on and off at that speed, we would not be able to see the change occurring. Therefore, we'll add a simple one-second delay, as shown in Fig.6. Now drag a Delay between the two outputs, double click the Delay icon and configure its Properties for a 1s delay – don't forget to select seconds, not milliseconds or microseconds (see Fig.7).

Are we finished? Not quite – as things stand, we turn our LED on for 1s, and then we turn it off. However, we do not hold the LED off, which means it will turn on again so fast that it appears to be permanently on. We need to add another Delay icon *after* we turn the LED off, as show in Fig.8. This completes the flowchart, and the simple LED flasher is now finished.

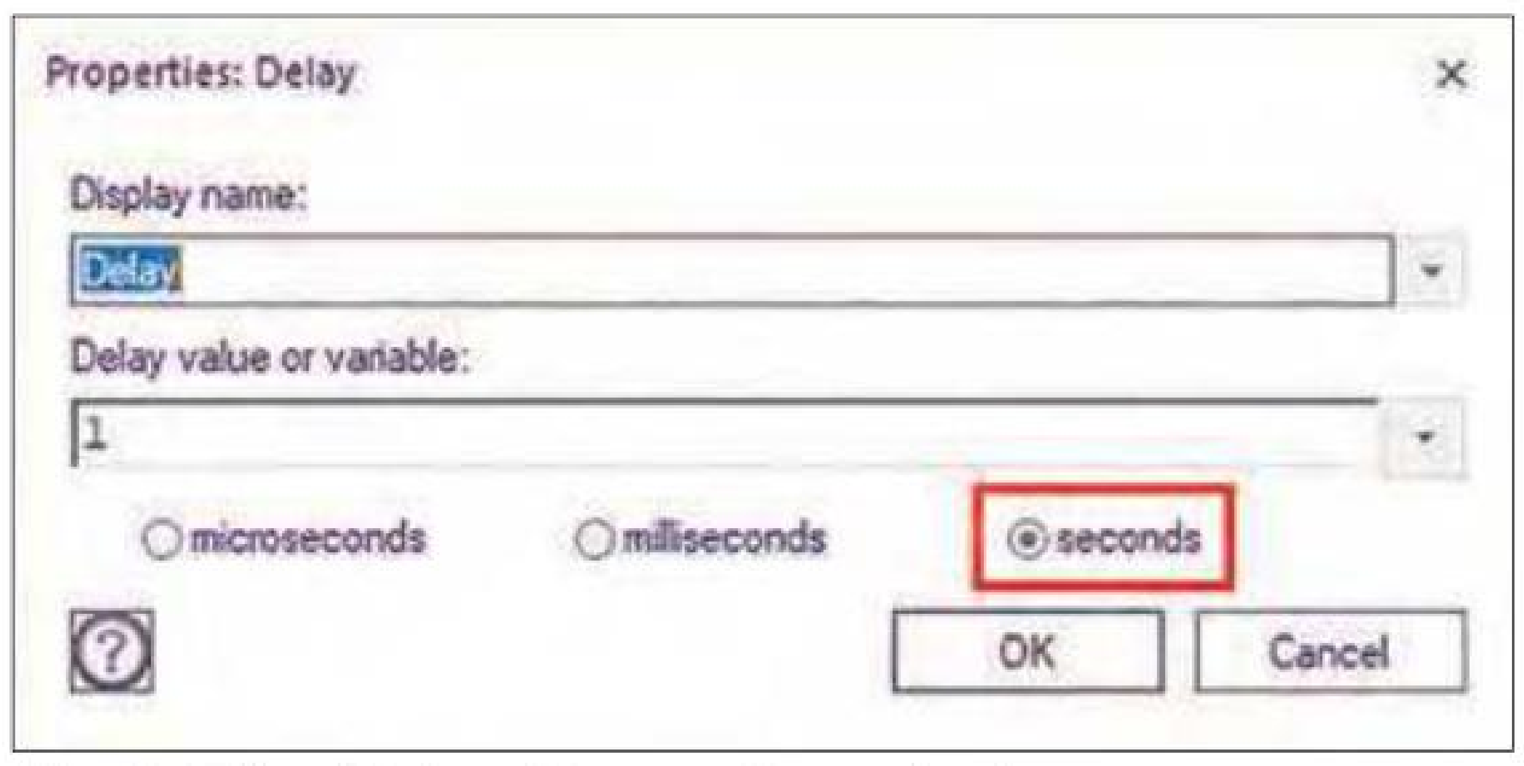
Simulation

The next step is to run our program in simulation to check it works as required. Then we will write it to hardware and make an actual LED flash.

To simulate, we first add an LED to the 2D Dashboard Panel from: Components Libraries > Outputs > LED Section. Choose the device called '5mm, Panel' – again, we choose this particular component because it's guaranteed to be available if you are using the free version of Flowcode.

When you add components, they will automatically be added to the centre of the 2D Panel. If you can't see the component after it has been added, it might be too small (so zoom in), or it could have ended up in the wrong panel (ensure you do not use the 3D panel) or underneath another component (rearrange with your mouse). (To zoom, use the middle mouse wheel when the 2D Panel has been selected.)

Viewing the LED component's Properties window can be enabled via the View ribbon > Component properties, or just right-click on the component on the 2D Panel and select 'Properties' (Fig.9a).


Properties: Delay

Display name: Delay

Delay value or variable: 1

○ microseconds ○ milliseconds ● seconds

Fig.7. The Delay Properties window.

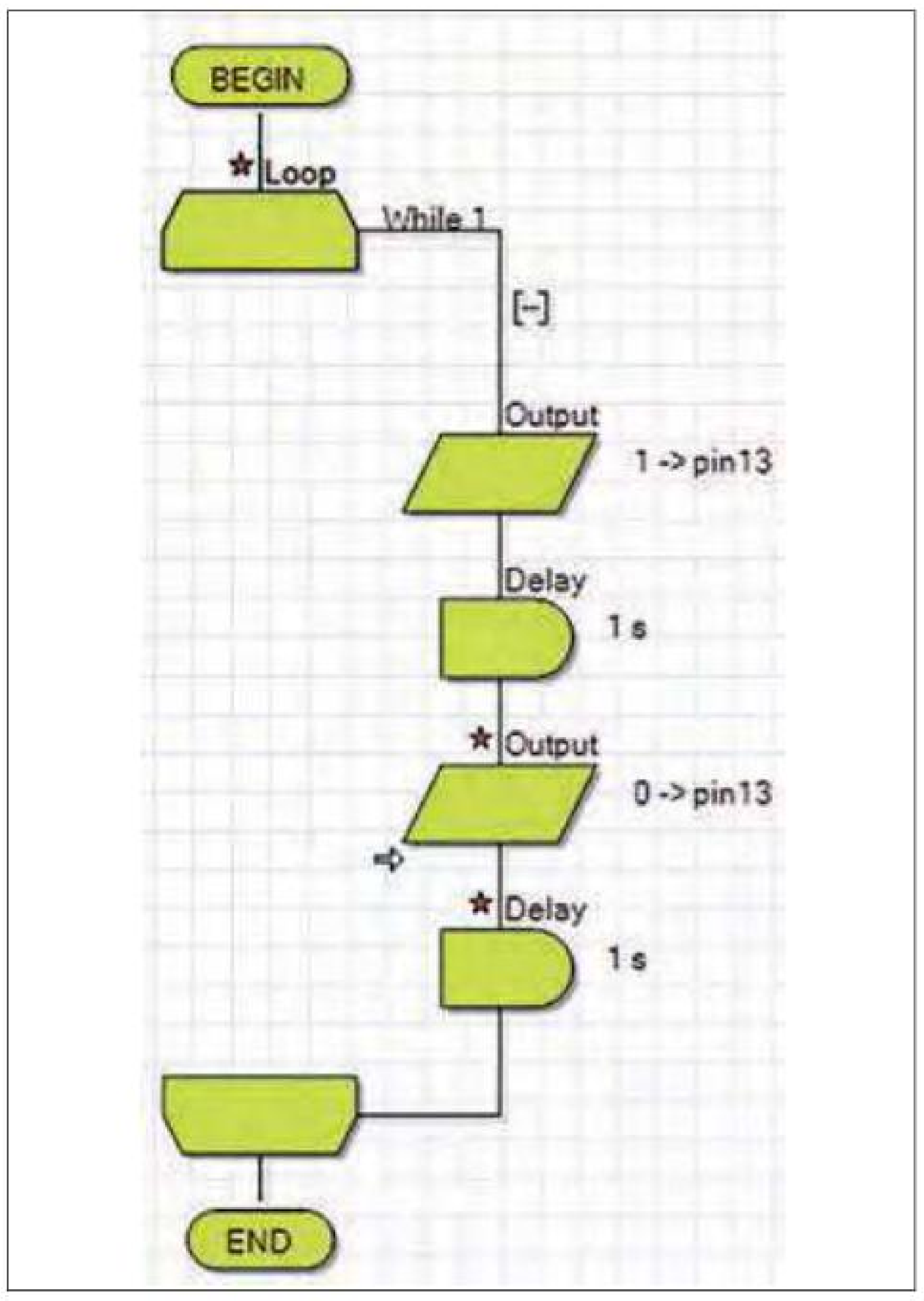


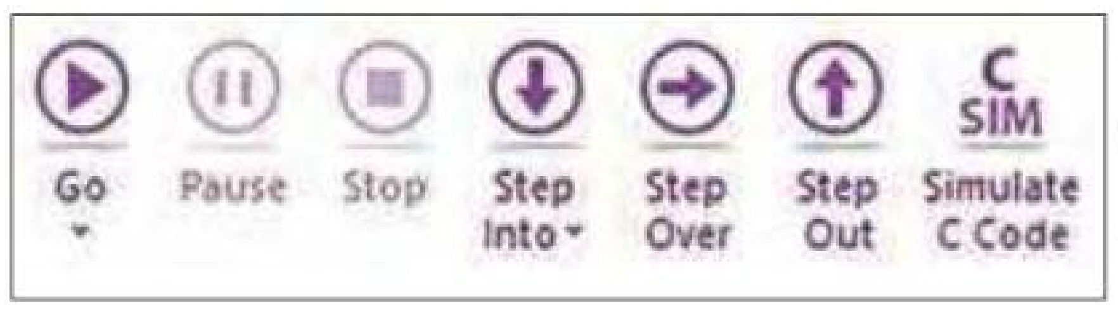
Fig.8. Completed one-second flasher.

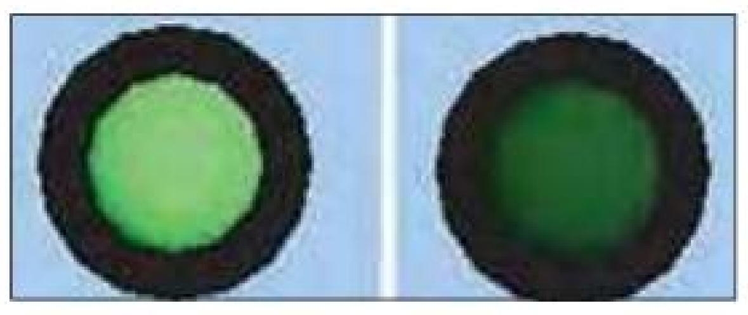
Once you have the LED's Properties visible, select the spanner icon and note that the value `$PORTA.0` is the default Connection setting. When using an Arduino Uno / RedBoard, I prefer the connection property to state the number marked on the PCB – in our case '13'. To do that, select `$PORTA.0` and untick 'Use Chip References'. Now select 'pin13' from the drop-down (Fig.9b) and the connection property becomes `$pin13` (Fig.9c).

Run the simulation

We're now ready to simulate the LED flasher. To do that, use the buttons from the Debug ribbon (see menus top of window), as shown in Fig 10.

The 'Go' (ie, 'play') button begins the simulation. Once in play mode, we can pause or stop our simulation. The two icons on the very right allow us to manually step through our program. As previously mentioned, microcontrollers operate at very high speeds – much faster than we can see – so we often need to manually step through each icon to check that our program is working correctly.





(L) Fig.10. Simulation control buttons. (R) Fig.11. Simulated flashing LEDs.

If we run our simulator, we will see that our LED flashes on for 1s and then off for 1s, as shown in Fig.11. Now, we'll move on to the next stage and transfer our code to hardware.

Transferring code to the RedBoard

The RedBoard/Arduino Uno are easy-to-program targets. If you are using a DIP Uno (microcontroller plugged into a holder), then the Windows drivers should work. If you are using a non-DIP (ie, surface-mount QTFP-type board), including the RedBoard, you will need to download CH340 drivers from: **https://bit.ly/pe-jan22-CH340**

Now check which port the board is connected to when plugged into your PC USB socket. Run the Device Manager (Windows icon, within the search window, enter device manager) and expand Ports (COM & LPT), as shown in Fig.12. This show which port has been assigned to the RedBoard. In my case, the connected RedBoard uses COM7. If I had the Uno connected and did not have Arduino IDE installed, I would just see 'USB Serial Device' as the device name.

To transfer the code to the hardware, select Build ribbon > Project Options, as shown in Fig.13a, which will open up the window in Fig.13b. You should already have the correct target selected, as we did that at the beginning. The clock speed is fixed for the RedBoard or Arduino, so you won't be able to adjust that. At the bottom of the Project information section, you will see 'Programmer Port' – select the correct port from the drop-down list (according to your Device Manager list), then select 'Modify'. Finally, select 'Compile to Target' (Fig.13a). After a short time, the code will be compiled and sent to the RedBoard, which will then start running it automatically and the built-in LED should be flashing on then off each second.

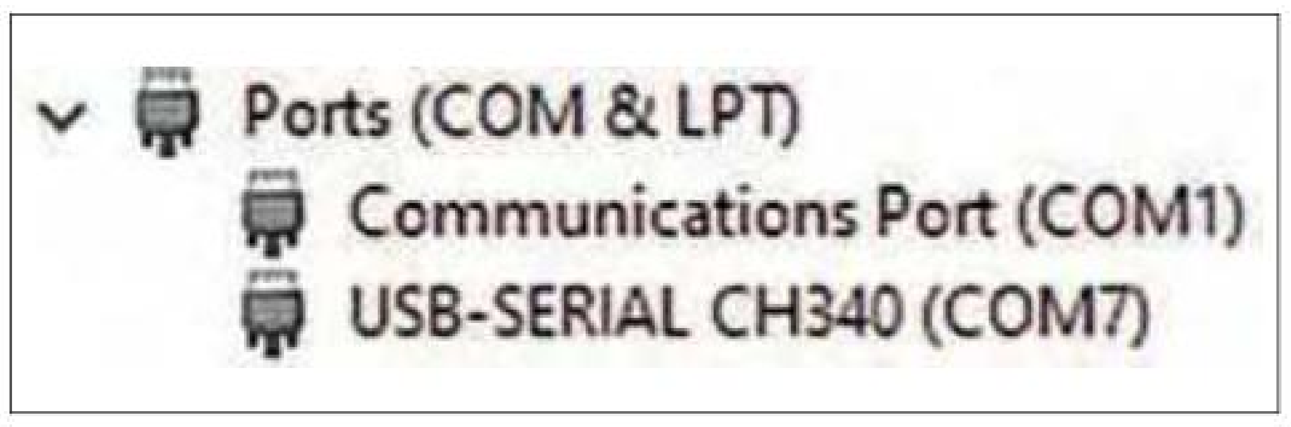
Let's just pause for a moment and consider what we've done. Without writing a line of code we have created a RedBoard/Arduino program, tested it in simulation, (hopefully!) verified that it works and then transferred the validated code to hardware and set it running. The program might be simple, but it's the process that counts – quite an achievement!

Developing the traffic light

Now that we've validated our Project Options with the simple LED flasher let's move on to something a little more ambitious – our traffic light design. Before you start, make sure the simulation is *not* running – you should see a bold run icon (Fig.10) and greyed-out stop and pause Icons. Our first goal is to create a traffic light simulation that looks like the one in Fig.14. (Remember, if the 2D Dashboard Panel is not showing, just select View ribbon > 2D Dashboard Panel to open it.)

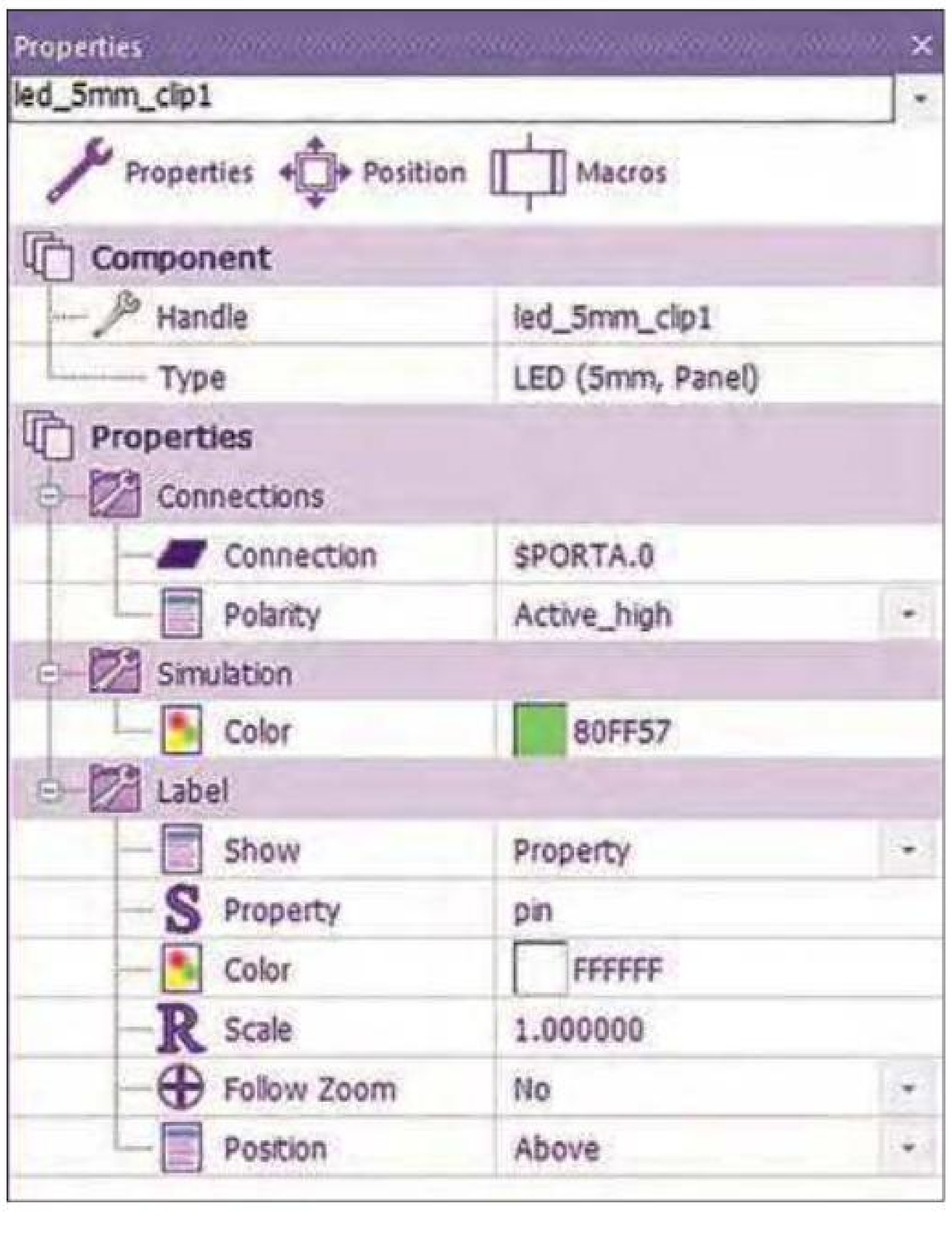
First, we'll change the background to a darker blue. On the top of the 2D panel, select the paint icon (a brush) then Background colour. Select the blue next to yellow on the bottom row.

Next, for the traffic light shape, select: Components Libraries ribbon > Creation,



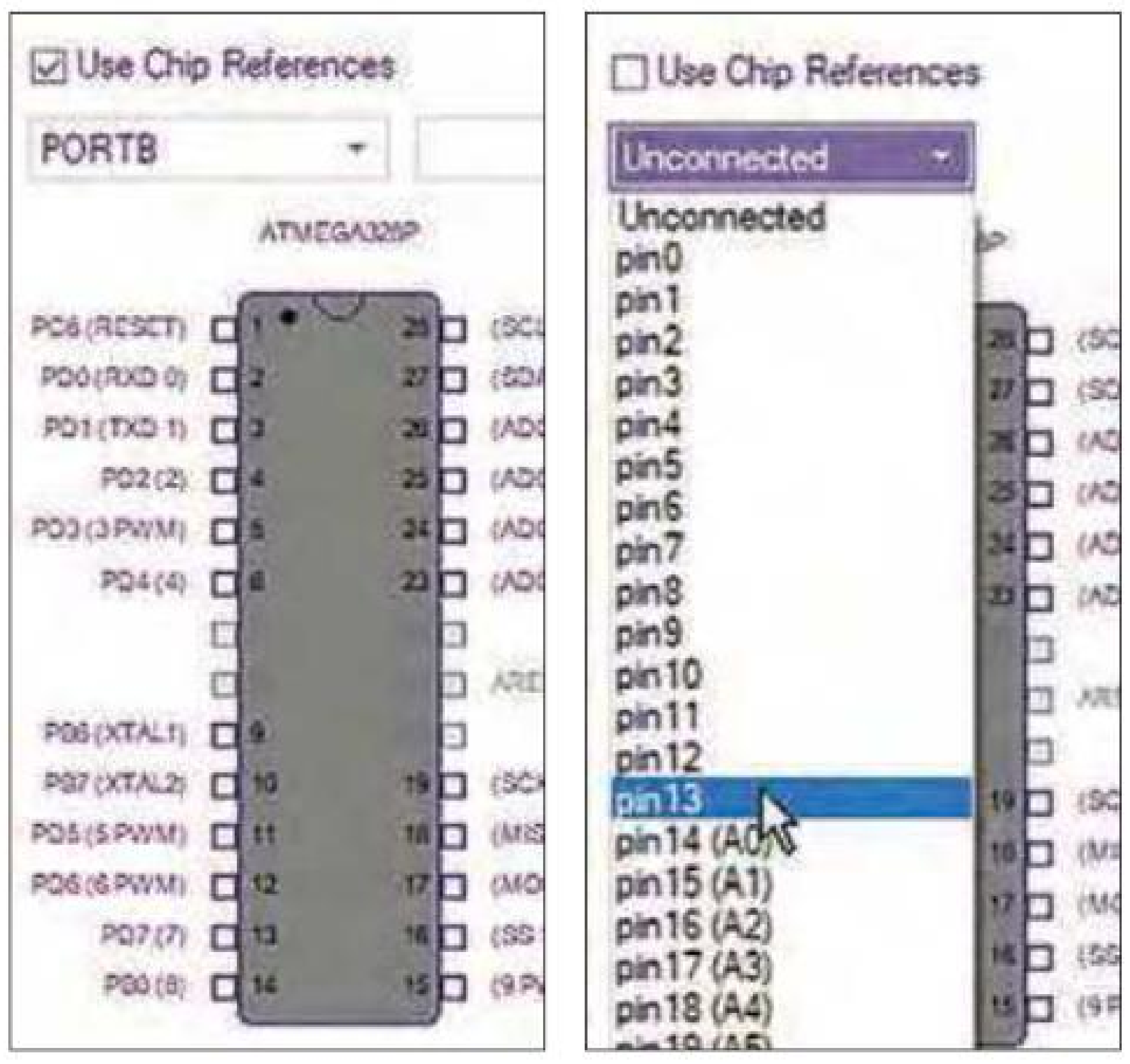
Ports (COM & LPT)
Communications Port (COM1)
USB-SERIAL CH340 (COM7)

Fig.12. COM ports in the Windows Device manager.



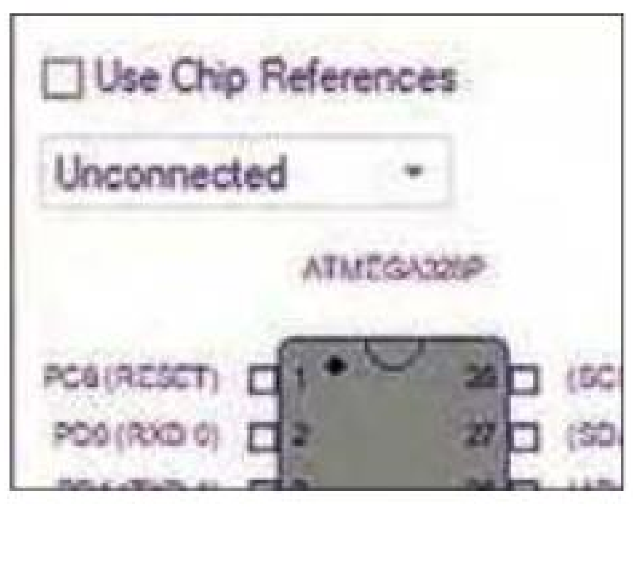
Properties
led_5mm_clip1
Properties | Position | Macros

Component	
Handle	led_5mm_clip1
Type	LED (5mm, Panel)
Properties	
Connections	
Connection	$PORTA.0
Polarity	Active_high
Simulation	
Color	80FF57
Label	
Show	Property
Property	pin
Color	FFFFFF
Scale	1.000000
Follow Zoom	No
Position	Above



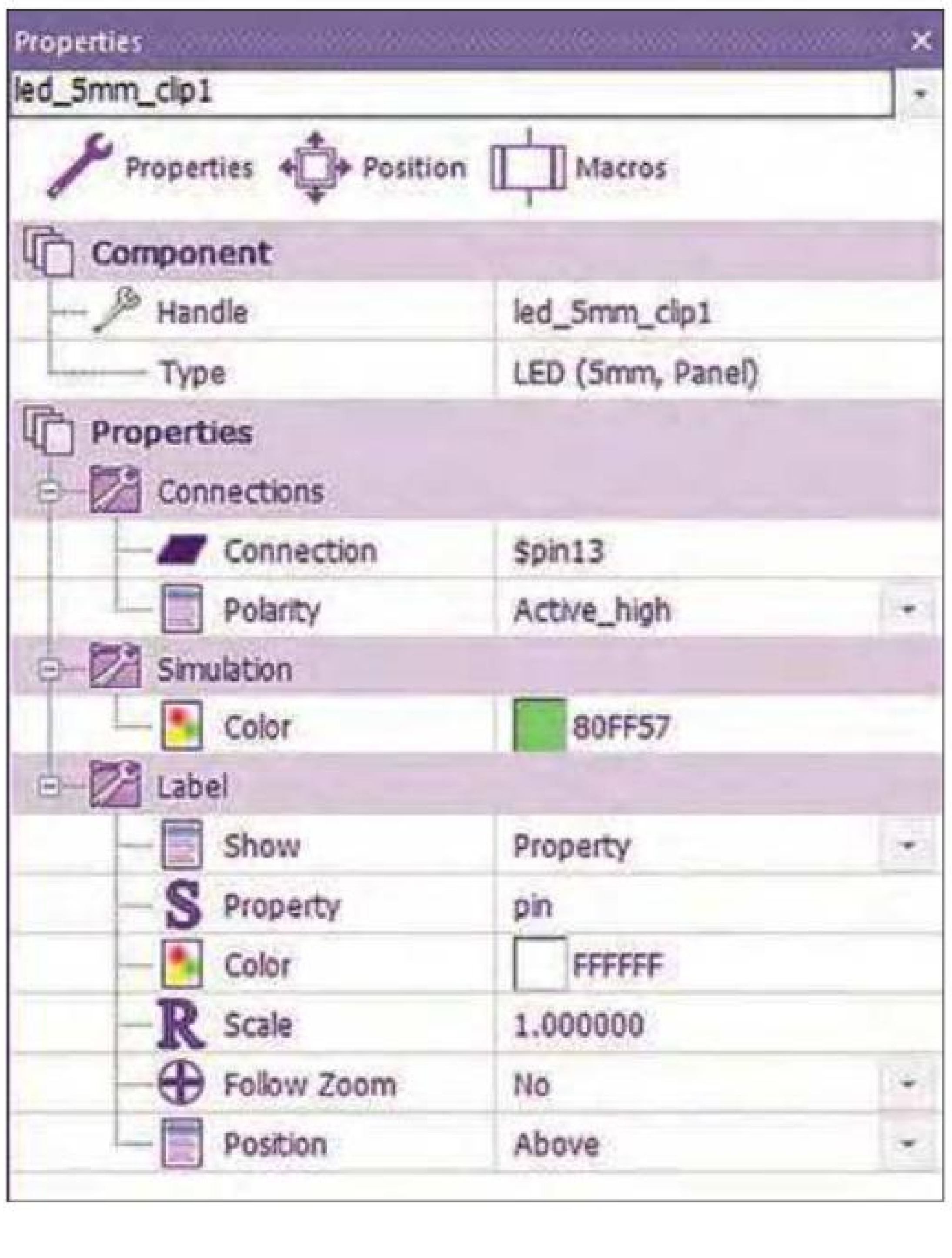
☑ Use Chip References
PORTB

☐ Use Chip References
Unconnected



☐ Use Chip References
Unconnected

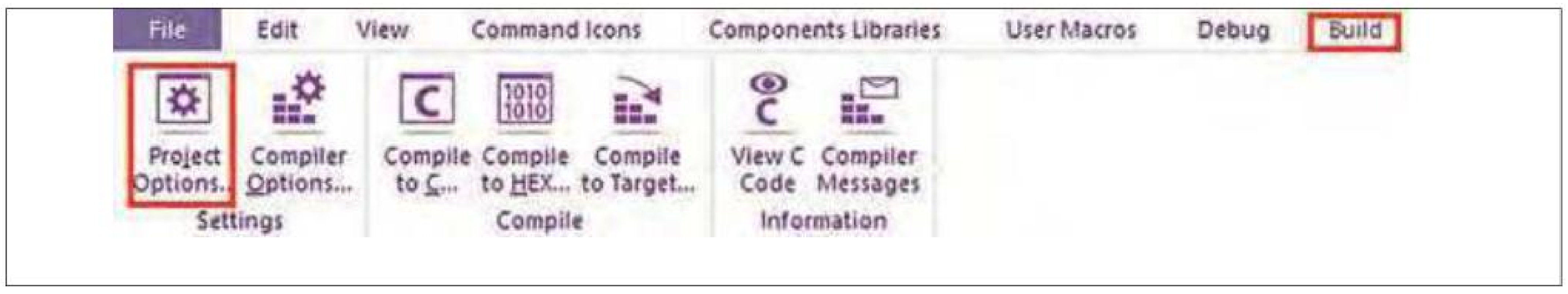
Fig.9. (L-R):
a) Default properties;
b) Choosing pin 13;
c) Amended Properties display.

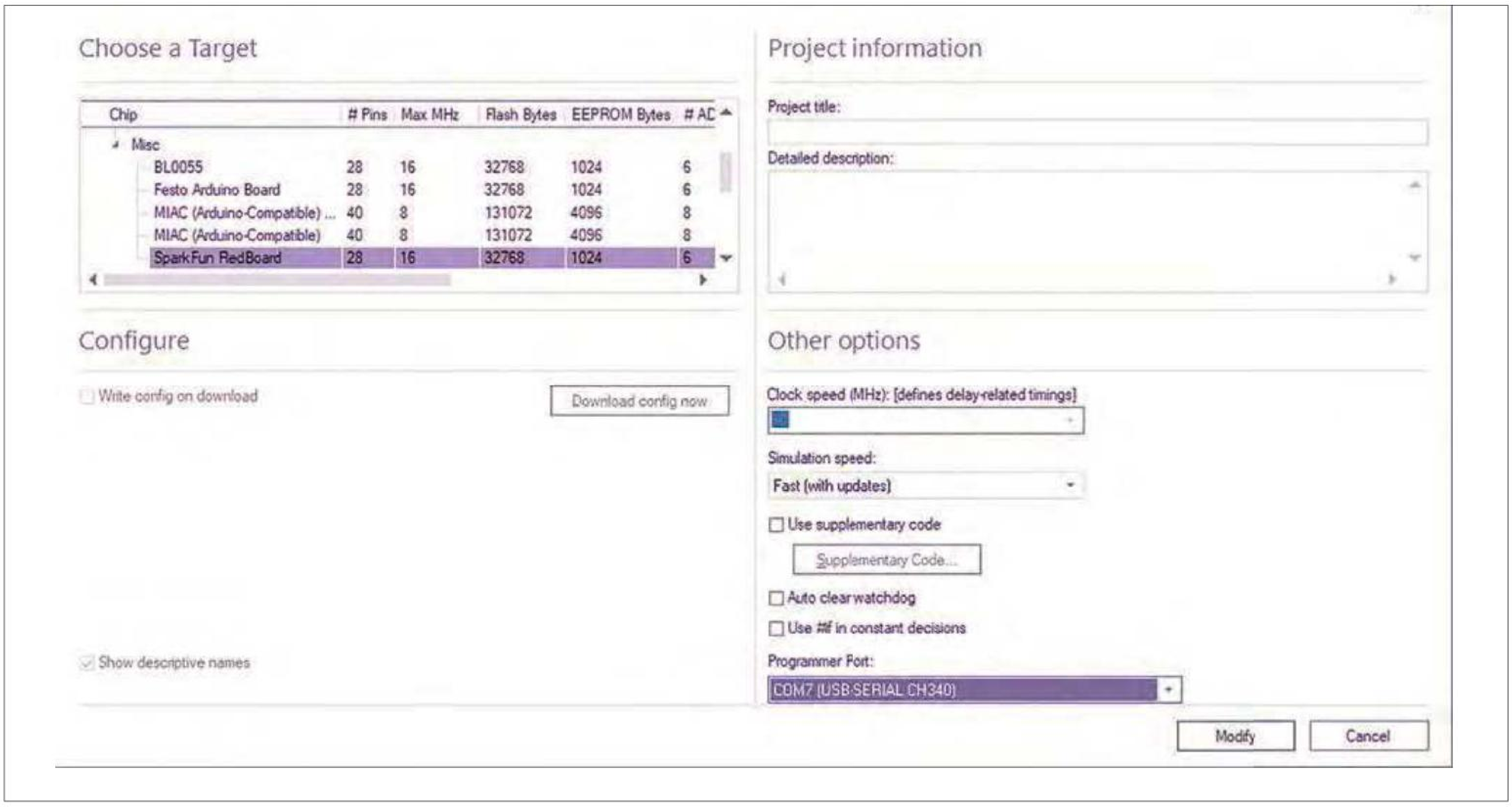


Properties
led_5mm_clip1
Properties | Position | Macros

Component	
Handle	led_5mm_clip1
Type	LED (5mm, Panel)
Properties	
Connections	
Connection	$pin13
Polarity	Active_high
Simulation	
Color	80FF57
Label	
Show	Property
Property	pin
Color	FFFFFF
Scale	1.000000
Follow Zoom	No
Position	Above

Fig.13. Accessing the Project Options window.


File
Edit
View
Command Icons
Components Libraries
User Macros
Debug
Build
Project Options...
Compiler Options...
Settings
Compile to C...
Compile to HEX...
Compile to Target...
Compile
View C Code
Compiler Messages
Information


Choose a Target
Configure
Download config now
Project information
Other options
Supplementary Code...
Modify
Cancel

Chip	# Pins	Max MHz	Flash Bytes	EEPROM Bytes	# AD
Misc					
BL0055	28	16	32768	1024	6
Festo Arduino Board	28	16	32768	1024	6
MIAC (Arduino-Compatible) ...	40	8	131072	4096	8
MIAC (Arduino-Compatible)	40	8	131072	4096	8
SparkFun RedBoard	28	16	32768	1024	6

☐ Write config on download

☑ Show descriptive names

Project title:

Detailed description:

Clock speed (MHz): [defines delay-related timings]

Simulation speed: Fast (with updates)

☐ Use supplementary code

☐ Auto clear watchdog

☐ Use ## in constant decisions

Programmer Port: COM7 (USB-SERIAL CH340)

then select 'Rectangle' from the 2D shapes section, then Add to 2D dash panel. Next, select the rectangle component on the 2D panel, then right-click and select properties – there are now three icons to choose from: 'Properties', 'Position' and 'Macros' (see Fig.15a).

For setting the rectangle's colour, we choose Properties. Change the colour by selecting the current colour Custom Tab, then change RGB values to `29, 29, 29` (a dark grey) – see Fig.15b.

Next, we want to create a second rectangle – select the rectangle you just created, right-click it, copy, then paste. Now we have two identical shapes called `shape_rectangle1` and `shape_rectangle2` (you can check which is which by examining their 'Handle' (ie, name) in Properties).

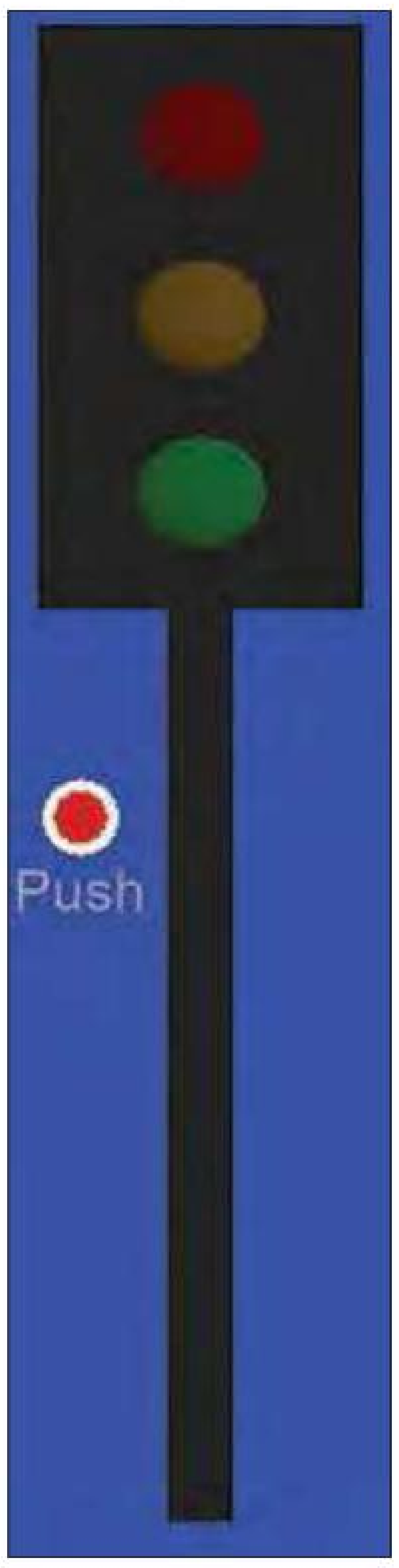


Fig.14. Traffic light model created on the 2D panel.

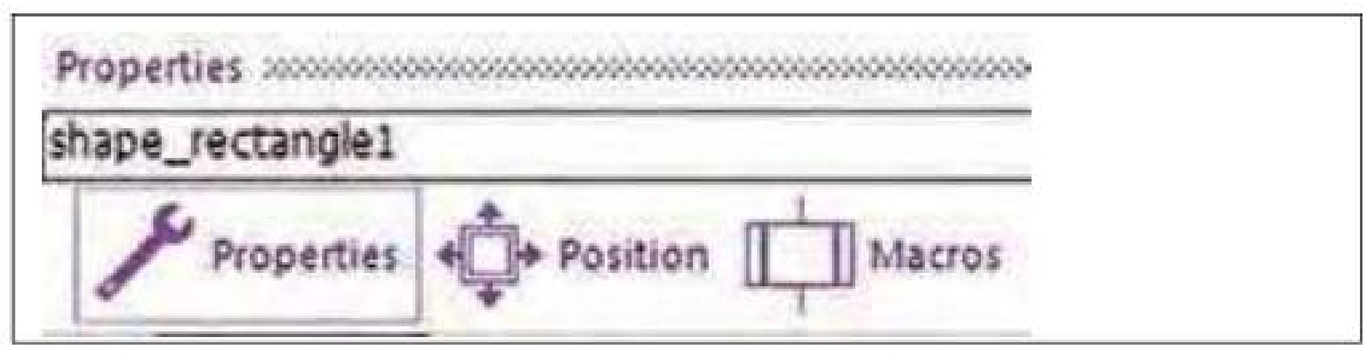
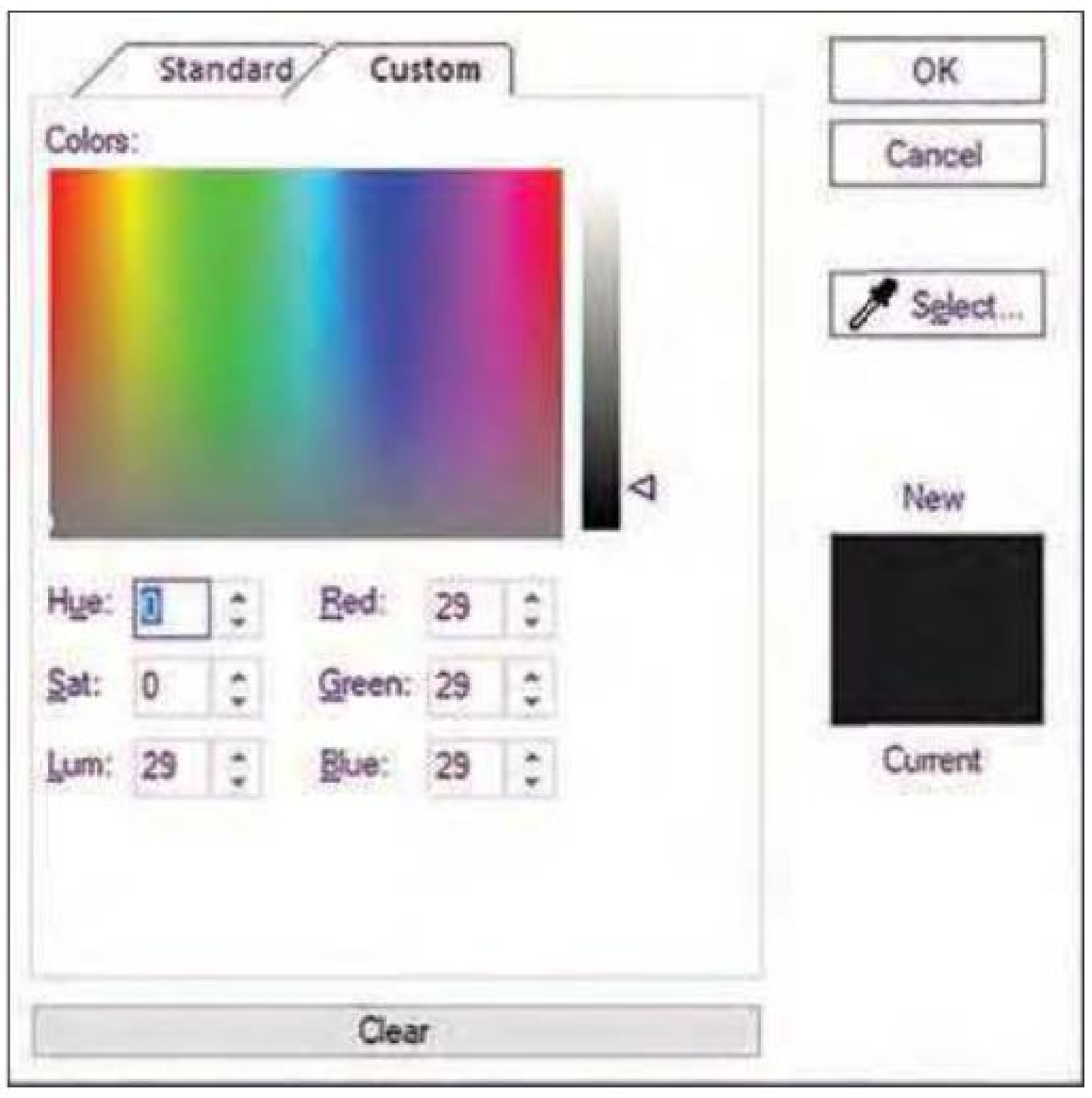

Properties
shape_rectangle1
Properties
Position
Macros

Fig.15. a) (above) Selecting a shape's Properties window; b) setting its RGB colour.


Standard
Custom
Colors:
OK
Cancel
Select...
New
Current
Clear

Hue: 0 Sat: 0 Lum: 29

Red: 29 Green: 29 Blue: 29

Let's create the top section of the traffic light. Select `shape_rectangle1`, then right-click and open its Properties. (Note: you can also use the top drop-down within Properties to select each component/shape.) Next, select the 'Position' icon, which allows you to enter both the shape's position and size, and enter the following:

```
World Coordinates X, Y, Z: 0, 164, 0
World Size Width, Height, Depth: 150, 271, 0
```

Now create the traffic light pole. Select `shape_rectangle2` and enter the following:

```
World Coordinates X, Y, Z: 0, -183, 0
World Size Width, Height, Depth: 30, 423, 0
```

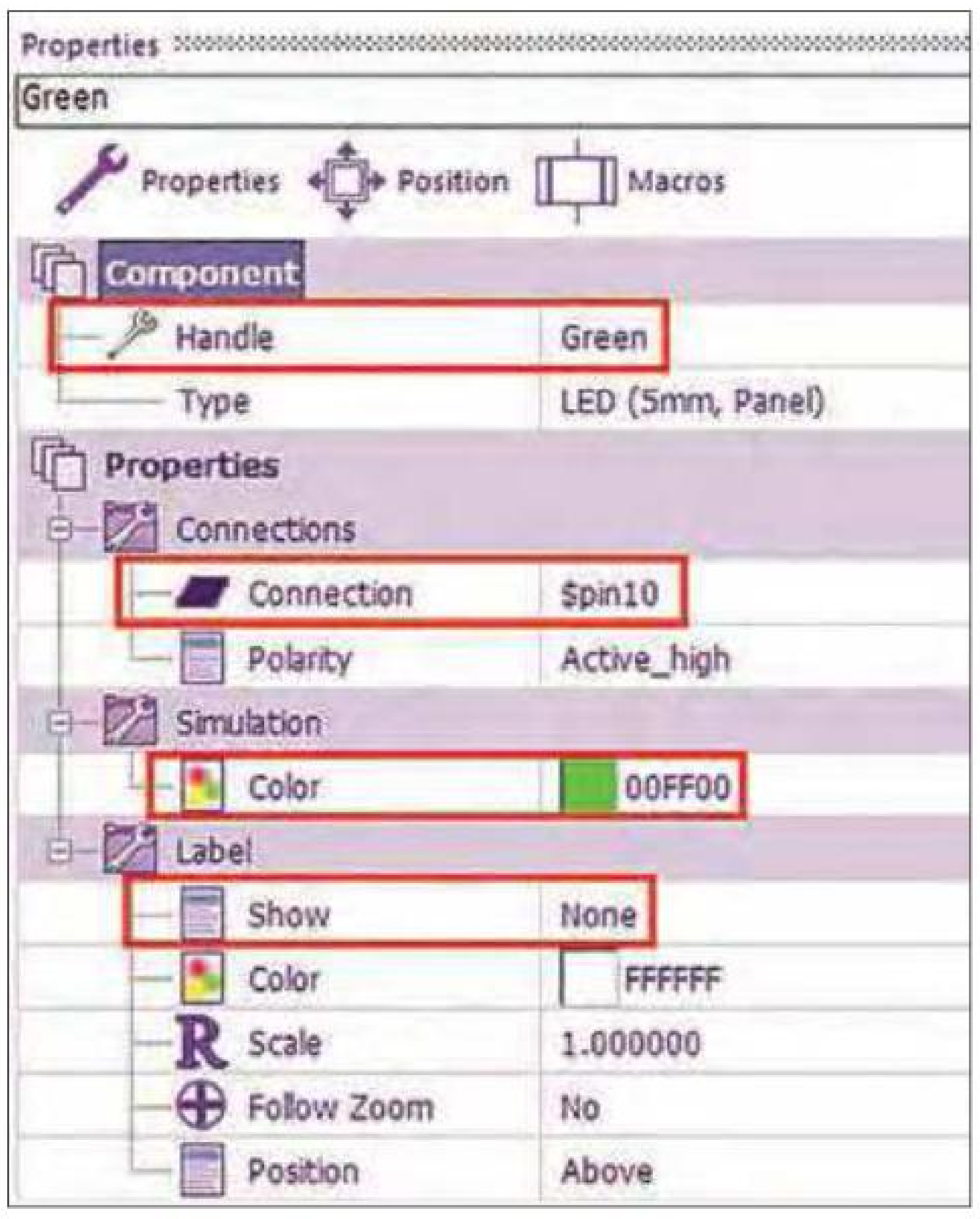
Next, we add the lights. You will already have one LED on the pane called `led_5mm_clip1`. This will be the green traffic light bulb. Select the LED from Properties and change the required position and size values:

```
World Coordinates X, Y, Z: 0, 82, 0
World Size Width, Height, Depth: 96, 83, 100
```

Now select the spanner icon; you will see that the Connection shows `$PORTA.0` as the default setting. As explained earlier, when using the Arduino Uno / SparkFun RedBoard I prefer to use the numbers that are silkscreened on the PCB. To do that, select `$PORTA.0`, and in the pop-up window untick Use Chip References and select pin10 from the drop-down, so that the LED's Connection Properties become: `$pin10`. Then, set the following additional properties:

`Polarity = Active_high`
`Color = 00FF00` (click Custom tab and enter `RGB = 0, 255, 0`)

(Note: in the Properties panel, the Color value is in hex and displayed 'in reverse' using the BGR (blue-green-red) format, ie, `BBGGRR`. In the custom panel you enter decimal values,



Green

Handle	Green
Type	LED (5mm, Panel)
Connection	$pin10
Polarity	Active_high
Color	00FF00
Show	None
Color	FFFFFF
Scale	1.000000
Follow Zoom	No
Position	Above

Fig.16. Green LED Properties.

for example to create `FF`, you enter `255`. If you don't know the decimal equivalent of a hex number, say BF, then use the Windows calculator in Programmers mode. Select HEX and enter BF. The calculator will display the decimal equivalent of hex BF, which is 191.)

Next we will set the LED's 'Label' to blank so that it's not superimposed on the traffic light simulation (note: since the Label is not displayed, you can ignore all of the other Label properties):

`Label, Show = None`

Finally, change the LED's 'Handle' from `led_5mm_clip1` to something more user friendly: `Green`. These Properties are summarised in Fig.16, and the 2D Panel result is shown in Fig.17 with the `Green` light added to the rectangle shapes.

All we need to do now is add the other two LEDs. Select and copy the `Green` LED and paste twice. To avoid confusion, rename the Handles of the two new LEDs `Red` and `Amber`. Then, for the `Red` LED we set the following Properties:

`Color = 0000FF` (Custom tab `RGB = 255, 0, 0`)
`Connection = $pin12.`
`World Coordinates X, Y, Z = 0, 246, 0`

Next, for the `Amber` LED:

`Color = 00BFFF` (Custom tab `RGB = 255, 191, 0`)
`Connection = $pin11.`
`World Coordinates X, Y, Z = 0, 164, 0`

That's the traffic light simulator almost finished. The final Component to add is a switch, located in Components > inputs. The name of the switch is Switch (Push Panel). (As before, I chose a free part.) Place it on the 2D Dashboard with the following Properties:

`Connection = $pin2.`
`World Coordinates X, Y, Z = –95, –68, 0`

I added a label displaying the word 'Push' below the switch using 'Static Text'. To do this, I used the search feature found on the far left of the Components Libraries ribbon. Click on the magnifying glass and enter 'static'. The results show static text is found in: Components > Creation > 2D Shapes. Now add that to the 2D Dashboard panel.

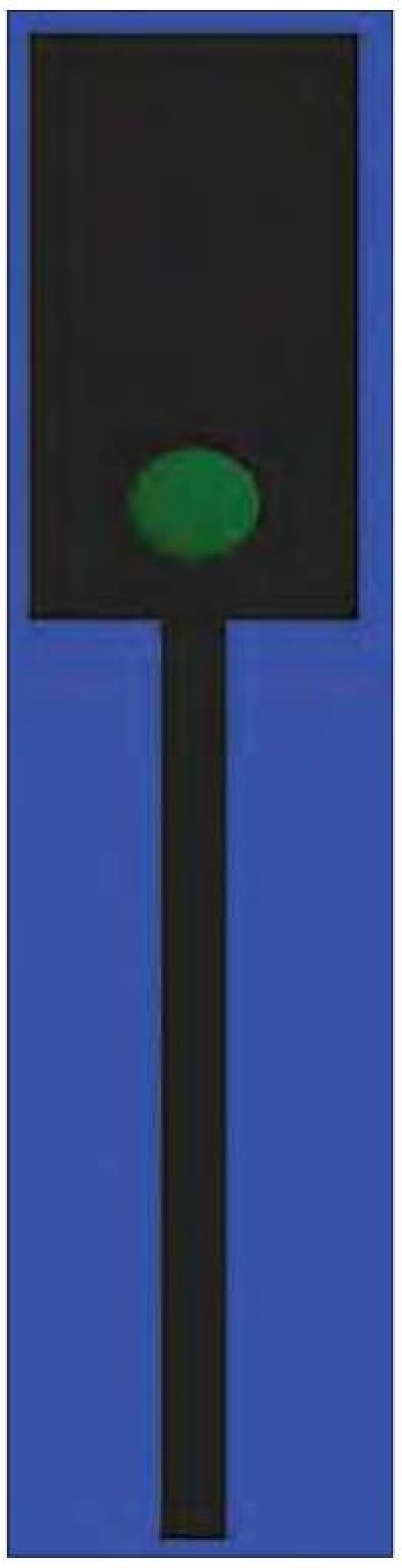


Fig.17. Traffic light with just the Green LED added

Drag, resize and 2D/camera views

Last, a quick note about using the 2D Panel. All the items added to the panel can be dragged or resized with these tools:

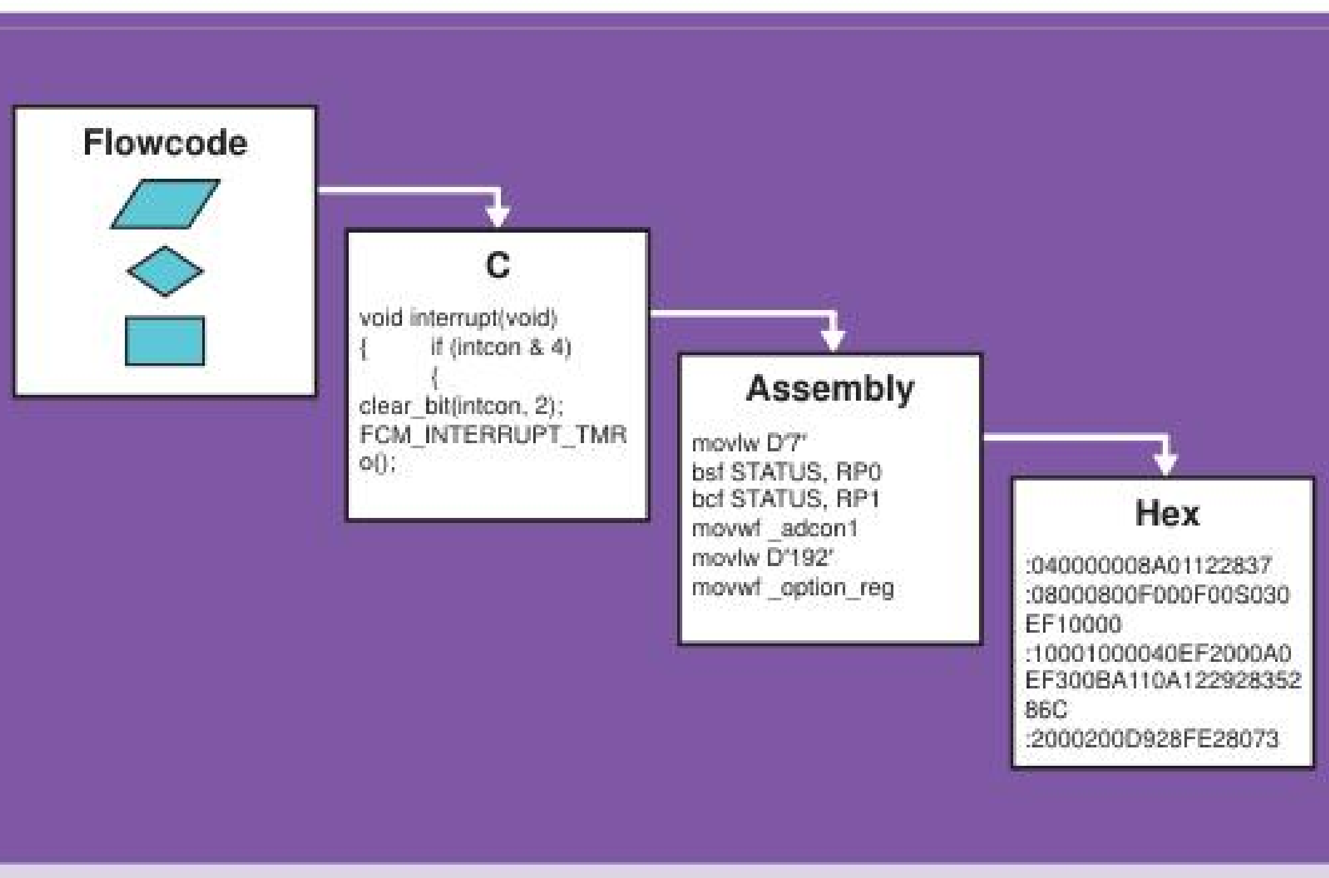
If the symbols are different to what's shown here, then you are in camera mode. To change .back to 2D Panel mode click this icon:

Next month

We've covered a lot of detailed, but important ground in this article. Next month, we will complete this mini project by creating our traffic light flowchart, running it in simulation mode and then on actual hardware – both the RedBoard and a PIC.

Martin Whitlock is Applications Engineer at Matrix TSL – the company behind Flowcode.

Try Flowcode for *free!*



```
void interrupt(void)
{         if (intcon & 4)
          {
clear_bit(intcon, 2);
FCM_INTERRUPT_TMR
o();
```

```
movlw D'7'
bsf STATUS, RP0
bcf STATUS, RP1
movwf _adcon1
movlw D'192'
movwf _option_reg
```

```
:040000008A01122837
:08000800F000F00S030
EF10000
:10001000040EF2000A0
EF300BA110A122928352
86C
:2000200D928FE28073
```

We hope you've found this article interesting. If you'd like to try Flowcode for free then just go to **https://flowcode.co.uk/download/** and download the code. You'll get a 30-day free trial of the full version – but that's not all. Even after the 30 days are up your copy of Flowcode will continue to work, but at a reduced level with a limit on the size of program you can run and access to a more basic set of parts. However, for beginners it is still an ideal platform with which you can build and run programs, on for example, the Arduino Uno/RedBoard or a PIC 16F88 that we are using in this project.

Only when you are really sure that you want to use Flowcode do you need to buy *inexpensive* access to say a Raspberry Pi or Bluetooth module. (See: **https://flowcode.co.uk/buy/process/** for all the modules available and what they contain.) What's more, as soon as you buy *any* module, the restrictions on the size of your code are removed.

If you get stuck with anything relating to Flowcode (installation, software, creating flowcharts, compiling to hardware, hardware not working… then there are forums set up to help you: **https://www.flowcode.co.uk/forums**

PE discount!

One more thing – Flowcode is deliberately designed to be inexpensive, but *PE* readers can get a further 20% discount when they use the code **PE20** at checkout.

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 23

Holy socks, Batman! I simply cannot believe it's Crimble season again. I don't know whether I'm coming or going, I don't have a speech prepared, and I don't have a thing to wear. One problem is that there are so many fun things to do, but so little time to do them all. A related problem is that I'm doing so many fun things that my poor old noggin is jam-packed with 'stuff'; for example...

Toroidal transformations

For reasons that will be made clear in the fullness of time, I've been cogitating and ruminating on the maths associated with the topic of twisting a torus (plural tori), a.k.a. a donut (and it's not often you expect to hear yourself say that).

Actually, full-blown tori are still sometime in our future. Before we get there, let's start by imagining that we cut a strip of paper. Let's call the corners at one end of the strip A and C, while the corresponding corners at the other end are called A' and C'. Now visualise bending our strip around to form a circle (Fig.1a). If we join the two ends 'as-is' without twisting the strip so that A' is connected to A and C' is connected to C, we end up with a ring that has two edges (top and bottom) and two sides (outside and inside).

Now visualise what happens if we give one end of the strip a half twist before joining the two ends, such that A' is connected to C, and C' is connected to A. In this case we have created a Möbius strip (a.k.a. Möbius band a.k.a. Möbius loop) that has only one edge and one side (A -> A' -> C -> C' and back to A again).

I'm sure you've seen this before, but on the off chance you aren't convinced, why not try making one yourself just for giggles and grins. Finally, if we give the end a full twist before connecting the two ends, we return to having two sides and two edges. And so it goes – twists of 0, 1, 2, 3... result in two sides and two edges, while twists of 0, ½, 1½, 2½, 3½… result in one side and one edge.

So far so good. Now, suppose we create what we might call a 'cross-strip' (Fig.1b). In this case, we might call the corners at one end A, B, C, and D, while the corresponding corners at the other end are called A', B', C', and D'. Once again, let's start by visualising bending our strip around to form a circle and joining the two ends 'as-is' without twisting the strip such that A' is connected to A, B' is connected to B, C' is connected to C, and D' is connected to D. In this case, we end up with four edges (A -> A', B -> B', C -> C', and D -> D') and four sides (both sides of the plane delimited by A, C, C', A and both sides of the plane bounded by B, D, D', B).

Now for the questions... we'll start with the low-hanging fruit in the form of Q1: How many edges and sides will we have if we give one end of our cross-strip a full twist before connecting the two ends (so A' is connected to A, B' is connected to B, C' is connected to C, and D' is connected to D)? Q2: Only slightly harder, how many edges and sides will we have if we give one end a half twist before connecting the two ends (so A' is connected to C, B' is connected to D, C' is connected to A, and D' is connected to B)? Q3: This one makes my head hurt; how many edges and sides will we have if we give one end a quarter twist before connecting the two ends (so A' is connected to B, B' is connected to C, C' is connected to D, and D' is connected to A)? (The answers can be found at the end of this column.)

Electronics that work

Apropos of nothing at all, earlier today as I pen these words, my chum Steve Leibson posted a review of a rather interesting book called *Designing Electronics that Work* by Hunter Scott – see: **https://bit.ly/3qk3qBq**

I hold Steve in high regard, so if he says a book is worth reading, I believe him. In fact, Steve goes so far as to say: 'Whether you're a maker, hobbyist, novice design engineer, or one of those seasoned grey hairs who know how to hold their tongue at exactly the right angle when making adjustments, the PDF version of this books is free, so you should download a copy today.'

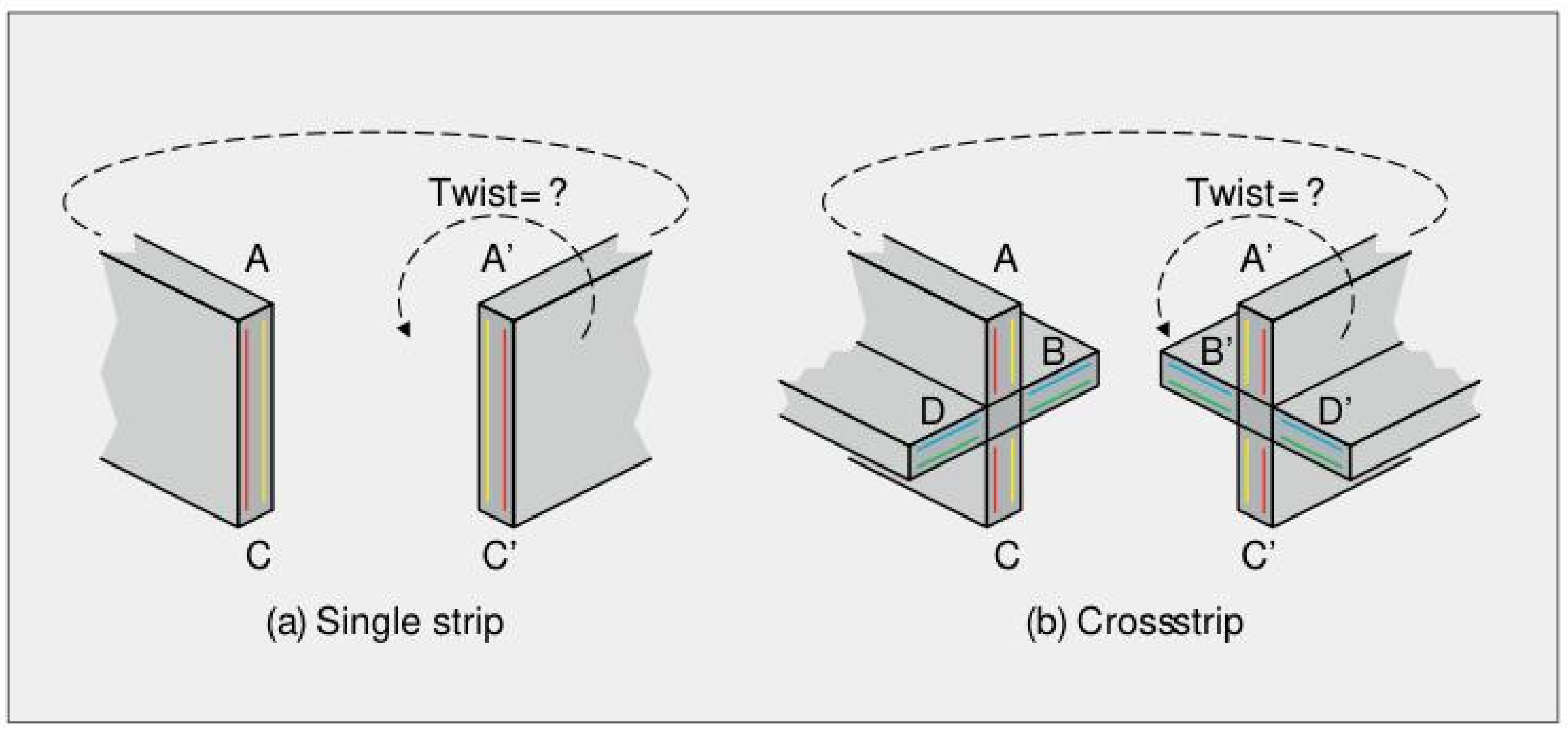


Fig.1. A simple strip of paper is more complicated than it looks!

Gas-heated soldering iron

Have you ever heard of a gas-heated soldering iron? Note that I didn't say 'gas-powered,' which might conjure up images of a splendid steampunk contraption. What I'm talking about is my very first soldering iron, which was literally a small cylinder of iron that was shaped into a point at the business end. The other end was connected via an iron rod to a wooden handle, which (in my case) was held by someone who didn't have a clue what he was doing.

This was circa 1969 and I was 12-years old at the time. I have no idea where this iron came from or who gave it to me. I think it was originally intended for working with metal, not electronics, but it was all I had, and I was happy to have it. I would heat my iron over the largest gas ring on our cooking stove in the kitchen until it glowed red-hot. Then I would race up the stairs to my bedroom to solder as many joints as I could before it cooled down too much to continue. This provided great exercise both physically (running up and down the stairs) and mentally (trying to work out why my circuit wasn't working due to dry/cold solder joints).

When I eventually managed to save enough of my pocket money to purchase an electric iron, I opted for a cheap-and-cheerful standalone device that came equipped with a small metal stand to hold the hot end away from the work surface (the bedroom floor in my case).

Apart from a single foray into a full-blown soldering station, which ended when I dropped it, thereby transmogrifying it into a paperweight, I've stuck with standalone soldering irons until just a couple of days ago. What happened was that the nice folks at Tilswall ran across my

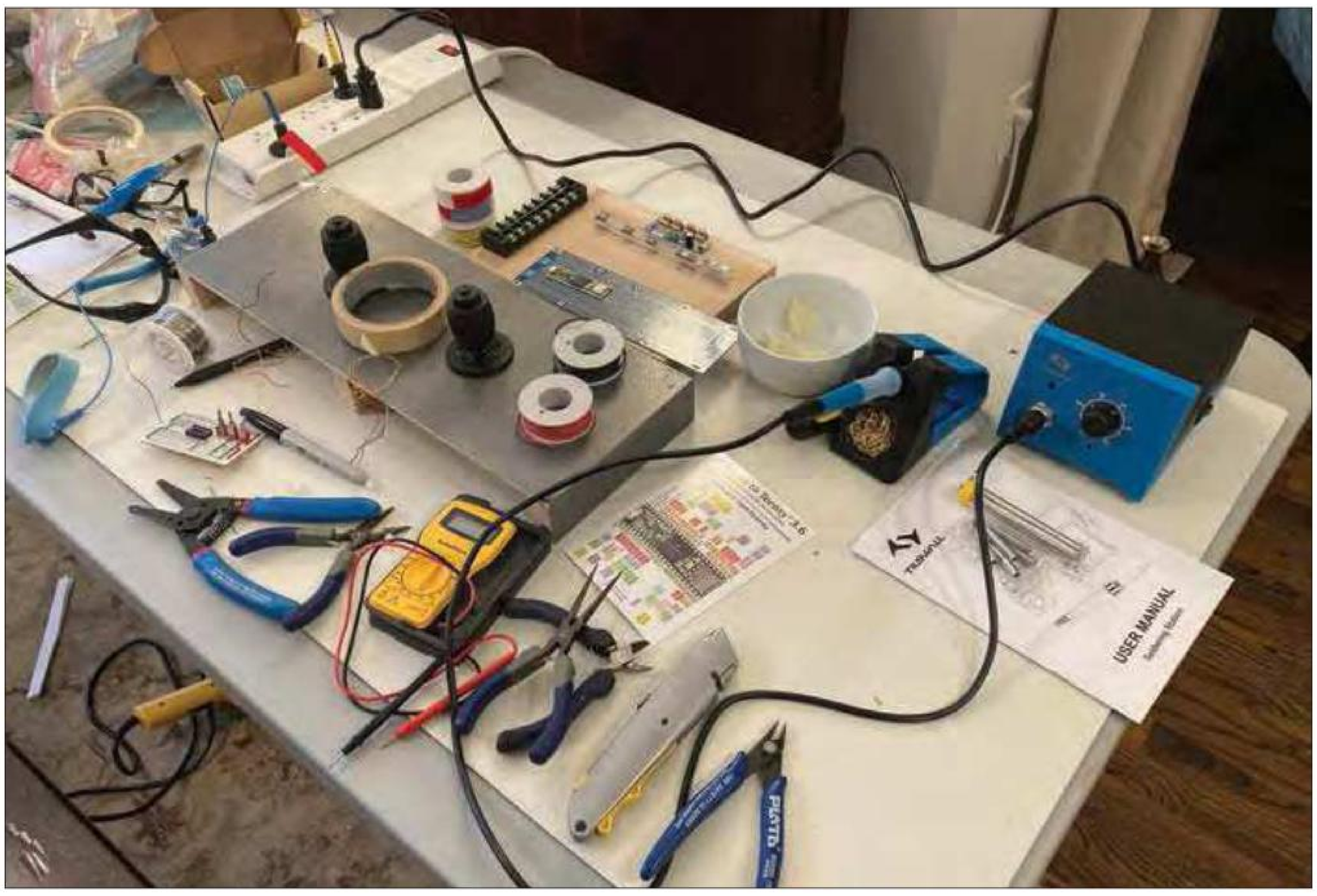


Fig.2. Work starts on my new robot head with my new Tilswall soldering station (upper right).

Cool Beans Blog (**https://bit.ly/2ZY4waZ**) and emailed me to ask if I'd like them to send me one of their soldering iron stations (**https://bit.ly/3BuhbiW**) to use on my hobby projects.

They caught me at just the right time, because – as I discussed in my previous column (*PE*, December 2021) – I was poised to commence work on a new robot head with servos and a corresponding control system. A few days later, my new Tilswall soldering station arrived and I set to work (Fig.2).

I've only been using this little beauty for a couple of days, but I have to say that I'm very impressed. This antistatic, ESD-safe station is a substantial unit that I believe offers amazing value for the price. It also comes with a collection of five different bits and a small spool of lead-free solder although – if the truth be told – I'm afraid I'll continue to use my trusty 63:37 silver-lead solder ('you can't teach an old Max new tricks,' as they say).

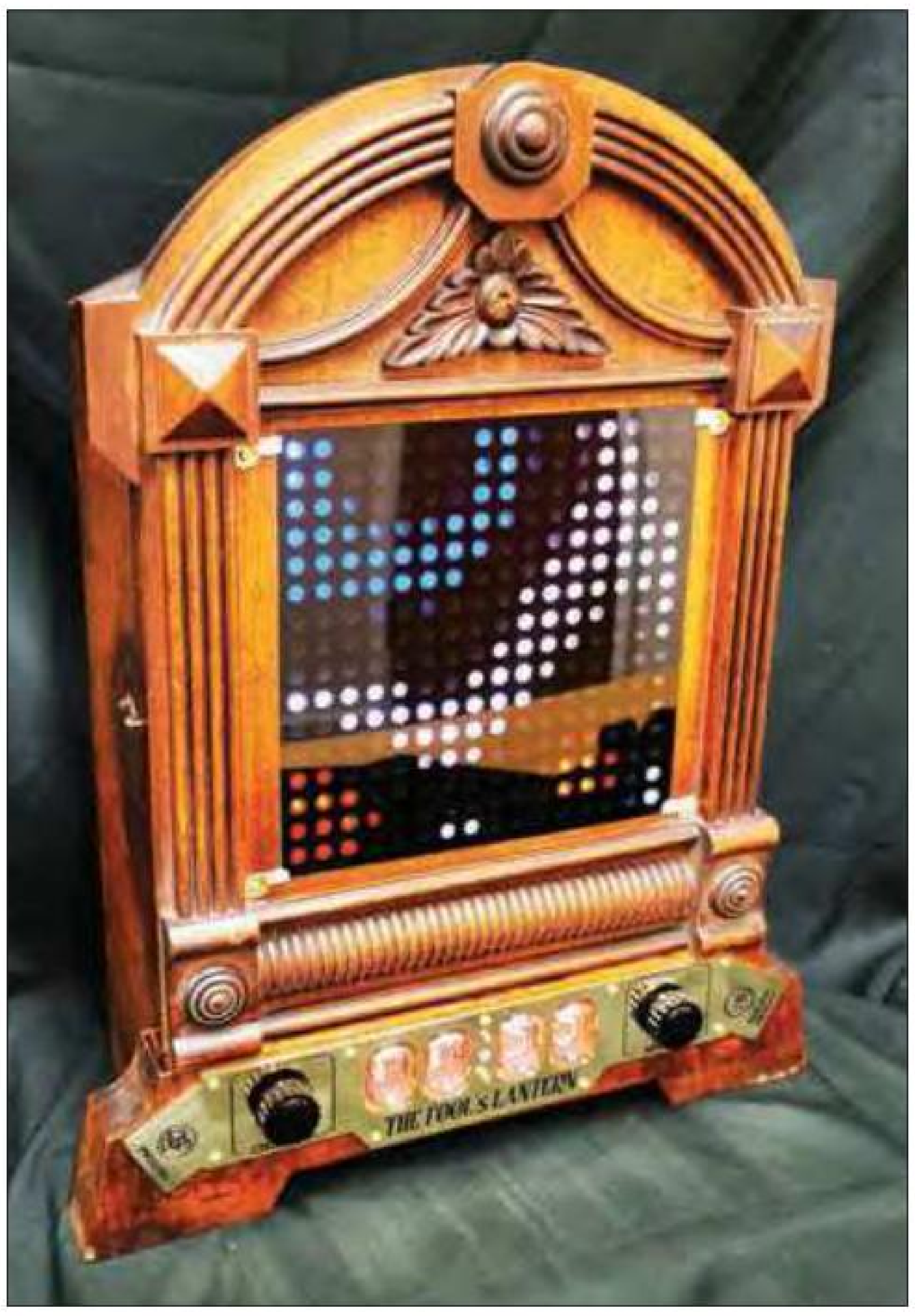


Fig.3. The *Fool's Lantern* (Image source: Bad Dog Designs)

Flashback to the 1970s

I'd like to say that I remember the 1970s as though they were yesterday, but a lot of Pooh Sticks have passed under the bridge since then. What I do remember is the abundance of groovy text fonts and the proliferation of psychedelic colour schemes. At that time, one of the big lighting effects that made its presence felt at the discos I attended as a student was from oil wheels. In fact, I just found a video on the *Funky Parrot* website (**https://bit.ly/3qidtHe**) showing a *Selection of 1970s Disco Lighting 6" Oil Wheels* that took me back in time (**https://bit.ly/3qkNgYr**).

The thing is – several times over the past few years – I've seen swirling effects presented on tricolour light-emitting diodes (LED) matrices that remind me of those old oil wheel displays. And each time I've seen something like this I've thought, 'I'd like to do something like that,' but I haven't known where to start.

Then, just when I was least expecting it, my chum Paul Parry who owns Bad Dog Designs (**https://bit.ly/3BWMjb9**) sent me an email with a link to a YouTube video of one of his latest creations that he's named the *Fool's Lantern* (**https://bit.ly/3H6GMCv**). This link was accompanied by a message saying, 'I made this earlier on this week and thought you might like it because it ticks lots of boxes.' Basically, this is one of Paul's famous Nixie tube clocks presented in an antique wooden cabinet and augmented by a 16×16 matrix of WS2812B tricolour LEDs (Fig.3).

The video shows lots of different lighting effects, but one that caught my eye was the swirling oil wheel-type effect that starts around 1:00 into the video. When I asked Paul about this, he replied: 'The code is pretty simple and it runs quite happily on a single Arduino Nano. If you search on Github for the FastLED library, there is an example called 'Noise,' which explains a lot better than I can how it works. I copied the code and removed the bits I didn't need. There are a few variables you can set for speed and level of depth – I just used a simple pot on an analogue input to alter the scale in real time.'

On occasion, I may have mentioned my 12×12 array of ping-pong balls, where each ball is equipped with a tricolour LED. In fact, I vaguely recall dropping it into the conversation in some of my *Cool Beans* columns (*PE*, June 2020 to January 2021 and April 2021 to July 2021). The point is, as soon as I get a free moment, I'm going to download the example code Paul talks about and tweak it to run on my ping-pong ball display. I shall, of course, report back in a future column.

Teachable moments

If you are an old hand at constructing electronic doodads, you may want to jump forward to the next topic. However, I do receive a lot of emails from readers of this column who are just starting out in electronics and – while I was commencing work on my new robot head – I jotted down a few notes that might be of interest to beginners.

Let's start with the concept of static electricity. When we walk around or rub against something, electrons can be transferred from one object to another, leaving one of the parties with an excess positive charge and the other with an excess negative charge. We call this, 'static electricity'. If we accumulate such a charge and then come close to a conductor with a path to ground, the result will be an electrostatic discharge (ESD) event, which may include a spark that makes life exciting for a while. If the conducting path happens to pass through the pin of a semiconducting device like a diode, LED, transistor, or integrated circuit (IC) (a.k.a. a silicon chip), then – much like Monty Python's *Dead Parrot* sketch – we may well find ourselves looking at an ex-semiconducting device with little tears running down our cheeks.

The solution is to ensure that everything – our components, our tools (eg, soldering iron), and ourselves – is at the same electric potential before we touch anything. As a reminder, you may recall that I described the Tilswall soldering station we discussed earlier as being antistatic and ESD-safe. Now you know why this is an important attribute to have in your soldering station.

Take another look at Fig.2, which features a folding table I set up in the corner of our family room to work on. My wife (Gina the Gorgeous) is more than happy to let me do this, just so long as everything is cleared away by the end of the day (I

Fig.4. Yours truly with his stash of copper braid that will protect a plethora of projects from ESD.

so want to have my own workshop). There are several things to observe in this image, starting with the antistatic mat covering the table. This mat is grounded through the yellow banana plug to the power strip. Similarly, the antistatic wristband (middle left-hand-side) is grounded through the blue banana plug to the power strip.

Now observe the small proto-board with the 18-pin IC socket and the three toggle switches sitting next to the blue wire strippers. Using IC sockets is recommended for two reasons. First, it lets us easily swap out our silicon chips if they are damaged for any reason, like static electricity, for example. Second, they let us easily confirm that the power and ground wires go to the right pins without forcing us to discover they don't by blowing up our chips.

The point is that, even when we are working on a board that is not yet populated with ICs or other semiconducting components, it's good practice to always work on an antistatic mat and wear an antistatic wristband. If you always do this so that it becomes 'second nature,' it will save you a lot of grief down the road. Trust me on this because I know whereof I speak. There's an old saying that goes something like, 'Experience stops you making mistakes, but it's making mistakes that gives you experience.' The real trick is to learn from someone else's mistakes.

As an aside, given a choice, when I'm building one of my larger hobby projects, like my *Prognostication Engine* (*PE*, March 2020), for example, I like to protect my cables by wrapping them in copper braid whose ends are connected to ground (you thread a bunch of wires through the hole running down the center of the braid, and then pull the ends of the braid, which causes it to shrink in diameter and hug the wires). The problem is that this braid is ferociously expensive. The solution is that my chum Rick Curl used to work for a company where they stripped this braid off large power cables and – unbelievably – threw it away because all they were interested in was the insulated core cables. As a result, several years ago, Rick gifted me with a lifetime supply (Fig.4).

Once you've wired your board, before you insert any ICs and connect the power supply, use your multimeter to check that everything is as it should be; ie, that all of the things that are supposed to be connected to the ground terminal are indeed connected to the ground terminal, that all of the things that are supposed to be connected to the power terminal are indeed connected to the power terminal, and – most importantly – that the power and ground terminals aren't connected to each other.

Next, still without populating your ICs, apply power to the board while being poised to immediately disconnect it if you hear any weird sounds, see any strange smoke, or smell any unexpected odors (all phenomena with which I have had much acquaintance over the years). This is a perfect time to recheck your IC data sheets to ensure that the power and ground pins are where you expect them to be, and to use your multimeter to ensure that these pins are connected to the power supply as they should be. Only now should you power the board down, insert the ICs, power it up again, and perform another check to confirm that everything is tickety-boo.

Feel the joy!

Returning once more to Fig.2, observe the grey wooden platform in the center of the picture. The two black protuberances are JH-D400X-R4 10K 4-axis joysticks, which you can find all over the place, including Amazon and eBay (Fig.5).

Unfortunately, they typically don't come with documentation, which can make life interesting for beginners. Before you discard the box that the pot came in, look for a small packet containing four tiny fixing screws that will be a pain in the nether regions to replace if you accidentally throw them away (once again, I speak from experience).

The hard plastic ring with the four holes can be lifted away. Less obvious is the fact that the soft inner plastic cover with the ripples can be slid up the joystick towards the knob (it may be a tight fit, but it will slide). This exposes four tiny holes in the corners of the case, which we will use to attach the joystick to our console (the grey wooden platform in my case). What we do is drill a 1.5-inch-diameter hole in the console surrounded by four small holes for the screws (use the hard plastic ring as a template). Push the knob up through the hole from the bottom while squeezing the soft inner plastic cover so that it also comes through the hole to be on top of the console. Keep on raising the joystick so it presses against the bottom of the console, slide the soft plastic cover down until it rests on the top of the console, return the hard plastic ring over the top of the knob, and use the four tiny screws to secure the beast.

Now, although these purport to be 4-axis joysticks, we should note that they are really only 3-axis devices that consist of three 10kΩ linear potentiometers (pots) and a normally open (NO) pushbutton switch on the top (the creators of these devices are using literary license to persuade us that the pushbutton represents a fourth axis of control).

Let's remind ourselves that a pot has three terminals, two of which are connected to either end of a resistive element (10kΩ in our case), while the third is connected to a movable wiper (Fig.6a).

A pot can be used as a rheostat (variable resistor) or as a voltage divider. We will be using our pots as voltage dividers. This means that we will be connecting power to terminal (1) and ground (0V) to terminal (2), or vice versa – it doesn't really matter which way round these go because we can swap the final readings over in software. With respect to this design, power will either be 3.3V or 5.0V depending on what sort of MCU we are using. If you are using a MCU like an Arduino Uno, which is powered by 5V and whose input pins support 0 to 5V, then you will use a 5V supply for your pots. In my case, I'm using a Teensy 3.6,

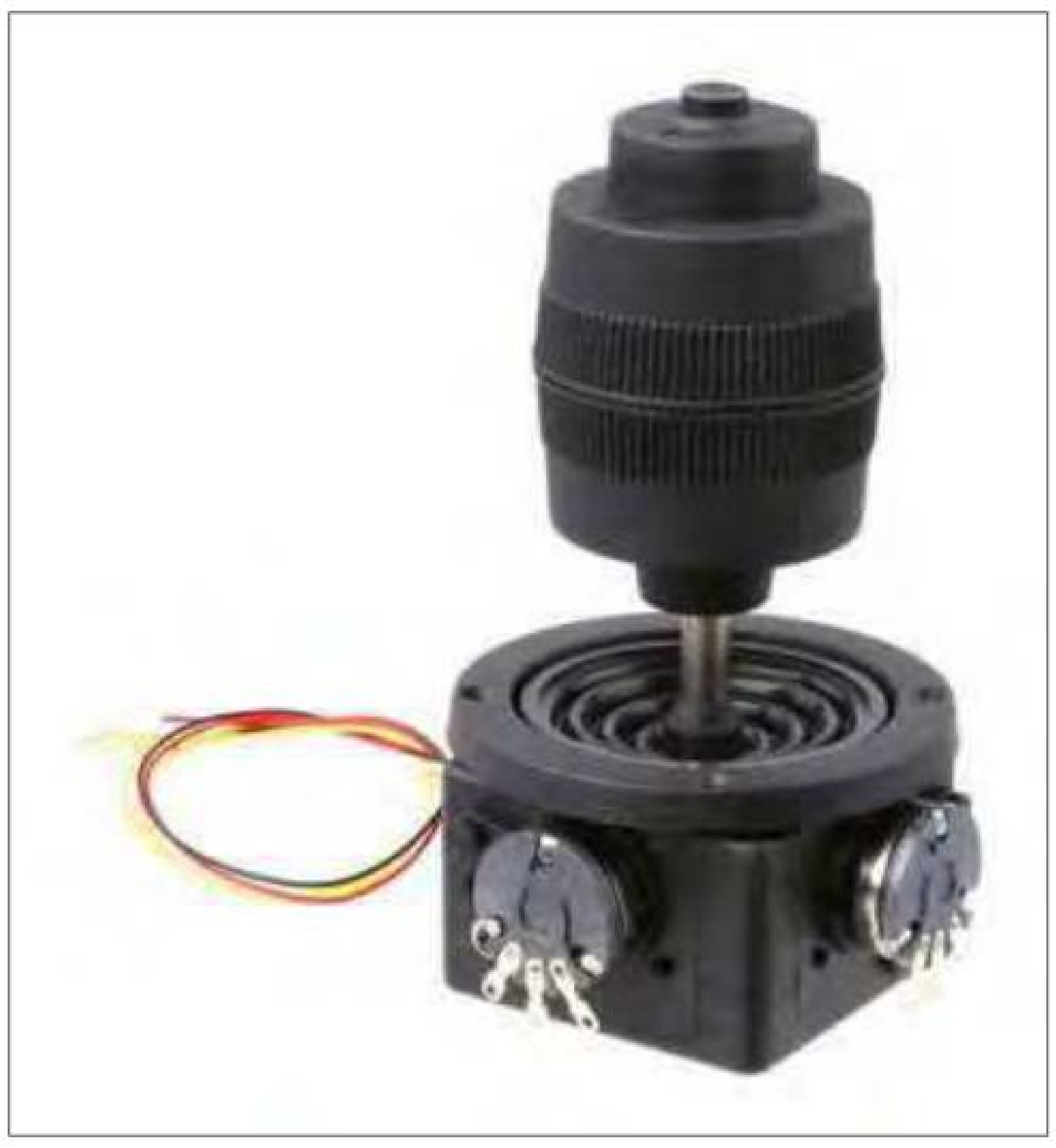


Fig.5. JH-D400X-R4 10K '4-axis' joystick.

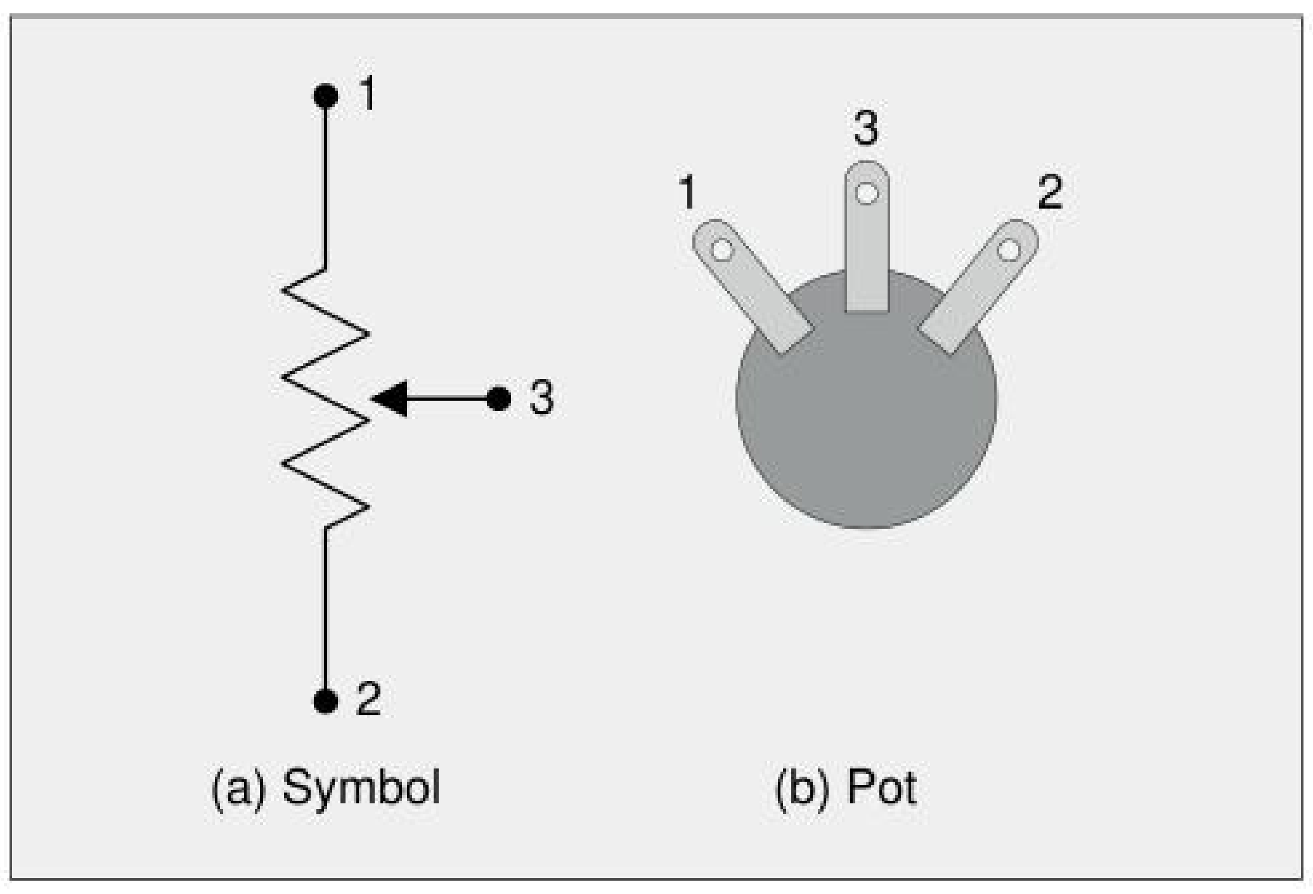


Fig.6. (a) Pot symbol; (b) backside view.

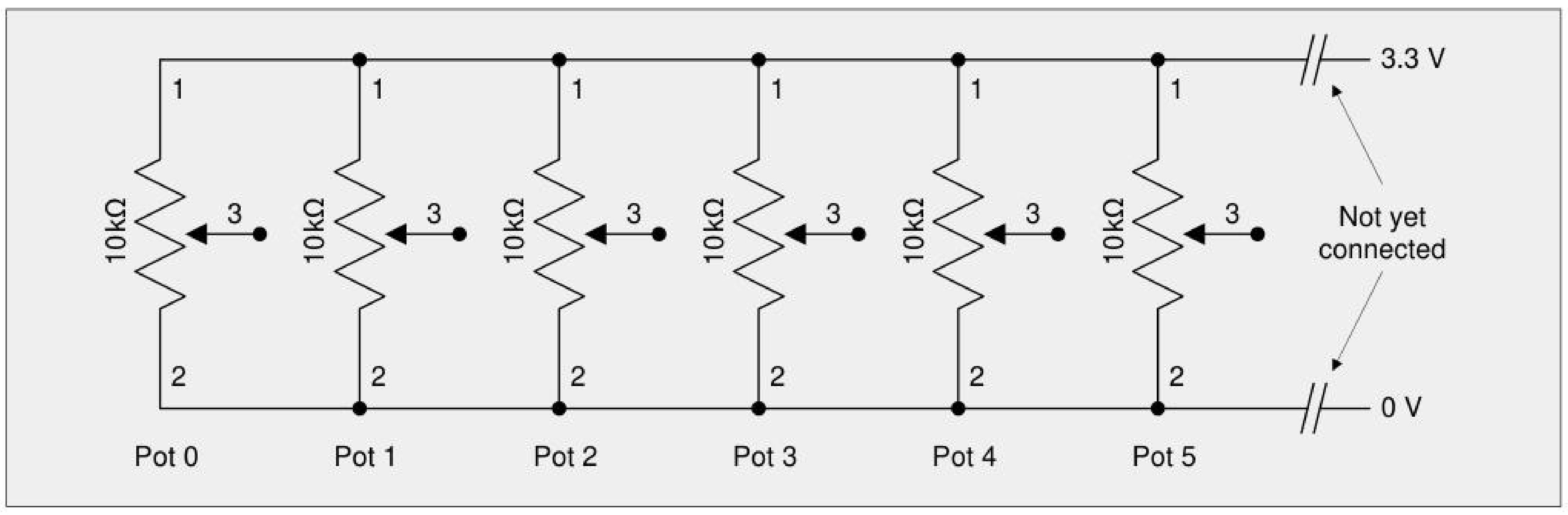


Fig.7. Six 10kΩ pots wired in parallel.

which is also powered by 5V but whose inputs will only tolerate 0 to 3.3V, so I'm using a 3.3V supply for my pots (this supply is generated by a regulator on the Teensy 3.6).

Returning to Fig.5, the two pots we can see on two of the sides respond to forward/backward and left/right motions of the joystick. The third pot, which is hidden inside, responds to our twisting the stick clockwise or anticlockwise. When we take our hand off the stick, it returns to its center position with respect to all three pots.

It's up to us to add wires to the forward/backward and left/right pots. When it comes to the third (internal) pot, observe the five wires coming out of the base. Two of these wires will be the same colour; these are the ones that are attached to the pushbutton switch. In my case, these two wires are yellow, but they are blue on the equivalent pots purchased by my co-conspirator Steve Manley in the UK. All we have to do is connect one of these wires to ground and the other to the input of our microcontroller (MCU). Actually, in my case, I'll be using a special switch debounce IC, but I'll be talking about this more in a future column. If you do connect the switch wire directly to the input of your MCU, then add an external 10kΩ pull-up resistor or declare this input as being of type `INPUT_PULLUP` in your code (assuming you are using the Arduino integrated development environment (IDE)).

The remaining three wires are connected to the internal pot. Once again, their colours may vary depending on the origin of the pots. In my case, these wires were white, black and red. My knee-jerk reaction was to assume that the white wire was the signal wire that was connected to the wiper, but it turned out that it was the black wire, so I'm glad I checked. And, speaking of checking...

Test, test, and test again

Let's remind ourselves that we currently have six pots that are each supposed to be 10kΩ. If you adopt a mantra of 'trust nothing; verify everything,' then the radiance of my smile will lighten your life. The main point to note here is that it's a lot easier to test your pots in isolation than it is when you've connected them all together.

In Fig.6b, I show the wiper terminal as being the one in the middle. This is the way things will be with more than 99% of the pots with which you come into contact, but it is possible to run across other configurations.

Here's the way I did things. For each pot, using my trusty multimeter, I measured between terminals 1 and 2 to ensure that the resistance value was indeed 10kΩ, give or take (GoT). Remembering that, in the case of this type of joystick, the stick automatically returns to its center position, for each pot I checked that the resistance between terminals 1 and 3 was 5kΩ GoT; similarly, between terminals 2 and 3. Finally, I checked that the resistance between terminals 1 and 3 varied between 0kΩ and 10kΩ, or vice versa, when the pot was pushed or rotated to its limits; similarly, between terminals 2 and 3.

You may feel that all this is overkill but – once again – let me reiterate that it's a lot easier to observe and identify problems when the pots are standalone than it is when you've connected them all together.

And, speaking of connecting them all together, what we are going to do now is to connect one side (which we call terminal 1) of all of our pots together. In the fullness of time, we will connect this side to our power supply. Similarly, we are going to connect the other side (which we call terminal 2) of all of our pots together. In the fullness of time, we will connect this side to our ground (0V).

The result is that our six pots are wired in parallel (Fig.7). Remember that I'm using a Teensy 3.6, so I've shown the power as being 3.3V, but it may be 5V in your case. At this stage, however, this is irrelevant because we haven't actually connected our pots to our power supply yet. Also, we haven't yet connected their wipers to our MCU's analogue input pins.

So, if you were to set your multimeter to measure resistance and connect one probe to the wire connected to all of the terminal 2s and the other probe to any of the wipers (this is something anyone might do), what resistance would you expect to see?

Would you be surprised if I told you that you should be seeing something in the region of 2.92kΩ. Also, that if you drive the pot whose wiper you are measuring to its full extreme one way, you will see a reading of 0kΩ, while driving it to its full extent the other way will result in a reading of 1.67kΩ.

If you say, 'Well, duh!' then you need read no further. Alternatively, if you are scratching your head and your face is scrunched up into a frown (which is not a becoming look on you, I'm afraid to say), then I would be happy to expound, explicate, and elucidate further. Unfortunately, our illustrious editor says we don't have the time or space to do this here, so I've written it up as a *Cool Beans Blog* (**https://bit.ly/3omhAzC**).

Next time

In my next column I hope to be able to show you the code that makes oil wheel-type swirly effects on my ping pong ball display. Also, we will be experimenting with more effects on our *SMAD* boards. And, of course, we will continue to work on adding motion to my robot head, with the ultimate goal of having it be able to turn to track me as I move around the room or to respond to any unexpected sounds. Until then, as always, I welcome your comments, questions, and suggestions.

Toroidal transformations answers

A1: There are still four sides and four edges, where the paths of the edges can be denoted as A -> A', B -> B'. C -> C', and D -> D'.

A2: There are two sides and two edges, where the paths of the edges can be denoted as A -> A' -> C -> C' and B -> B' -> D -> D'.

A3: There is only one side and one edge, where the path of the edge can be denoted as A -> A' -> B -> B' -> C -> C' -> D -> D'.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

PIC n' Mix

Mike Hibbett's column for PIC project enlightenment and related topics

Part 9: PIC18F Development Board

This month, we will add an LCD panel to our *Development Board*. Not because it especially needs one – the IoT platform Internet dashboard we introduced is far more flexible and convenient – but to demonstrate the capability, and test out one of our board's more complex peripheral interface, the SPI bus. Plus, of course, for some standalone applications a small, dedicated display is very useful.

First, let's add to the previous article by going into a little more detail about how to send data of your choice to the IoT dashboard, as shown in the **main.c** file from that article. The code itself is short, as shown in Listing 1, but there's a lot of complexity buried within it. Let's work through it.

TCP

The first two lines tell the ESP-01 module which website we are connecting to, and what protocol to use. Here, the connection will use the TCP protocol. This is a requirement for sending data to the Thingsboard website.

Website

The URL or website name we will connect to is: **demo.thingsboard.io**

Port number

The TCP Port number is 80. This number directs our data to a particular service on the website. Thingsboard implements their data input service on this port number, so that's what we specify.

PIC n' Mix PIC18F Development Board

The PCB for the *PIC18F Development Board* is available from the *PE PCB Service* – see the July 2021 section.

www.electronpublishing.com/product-category/pe-pcb-service/

Now, we can send as much data as we wish. Each message to be sent consists of two steps: Telling the ESP-01 module how many bytes of data we are going to send in the message, then the message itself.

Commands

We use the `AT+CIPSEND` command to specify the number of bytes we will send; as shown in line 4, this will be 180 bytes.

The bytes are sent using the `POST` command, as shown in line 9, where the command and our string of 180 bytes has been stored in the character array variable `esp01_buff`

The message

Now, the tricky part – and this did take a lot of trial and error to arrive at the correct message – exactly what do we need to send in that `POST` command?

We use the `sprintf` function to create this string, because we need to insert into the string a different value for voltage each time it is used. It's a long string, so let's break it down into parts:

```
POST /api/v1/ACCESS-TOKEN/
telemetry
```

This is the address (like a sub-directory) on the website where the data will be sent. As this string contains our unique `ACCESS-TOKEN`, that directory is specific and private to us. (Note that it's private because the `ACCESS-TOKEN` string is 16 characters long and randomly generated by Thingsboard, no one is going to guess it.)

```
HTTP/1.1\r\nHost: demo.
thingsboard.io\r\nAccept:
application/json\r\nContent-
Length: 23\r\nContent-Type:
application/json\r\n
```

These characters define the type of message we are sending. Thingsboard expects you to be sending an `HTTP POST` message, but the ESP-01 module only supports raw TCP messages, which is a lower-level communication protocol. By sending these characters, we are effectively implementing the HTTP protocol ourselves. Thankfully, the message is a simple fixed-format string, so once you know what to send (and finding that out was a challenge!) it can be hard coded into your program, as shown above.

Listing 1. Sending data over the ESP-01.

```
uart2_putstr("AT+CIPSTART=\"TCP\",\"demo.thingsboard.
io\",80\r\n");
parse_response(1000);

uart2_putstr("AT+CIPSEND=180\r\n");
parse_response(500);

sprintf(esp01_buff, "POST /api/v1/ACCESS-TOKEN/telemetry
HTTP/1.1\r\nHost: demo.thingsboard.io\r\nAccept:
application/json\r\nContent-Length: 23\r\nContent-Type:
application/json\r\n\r\n{\"SolarVolts\": %1.3f}\r\n",
solarPanel_volts);

uart2_putstr(esp01_buff);
parse_response(1000);
```

All Listings are available for download from the January 2022 page of the *PE* website.

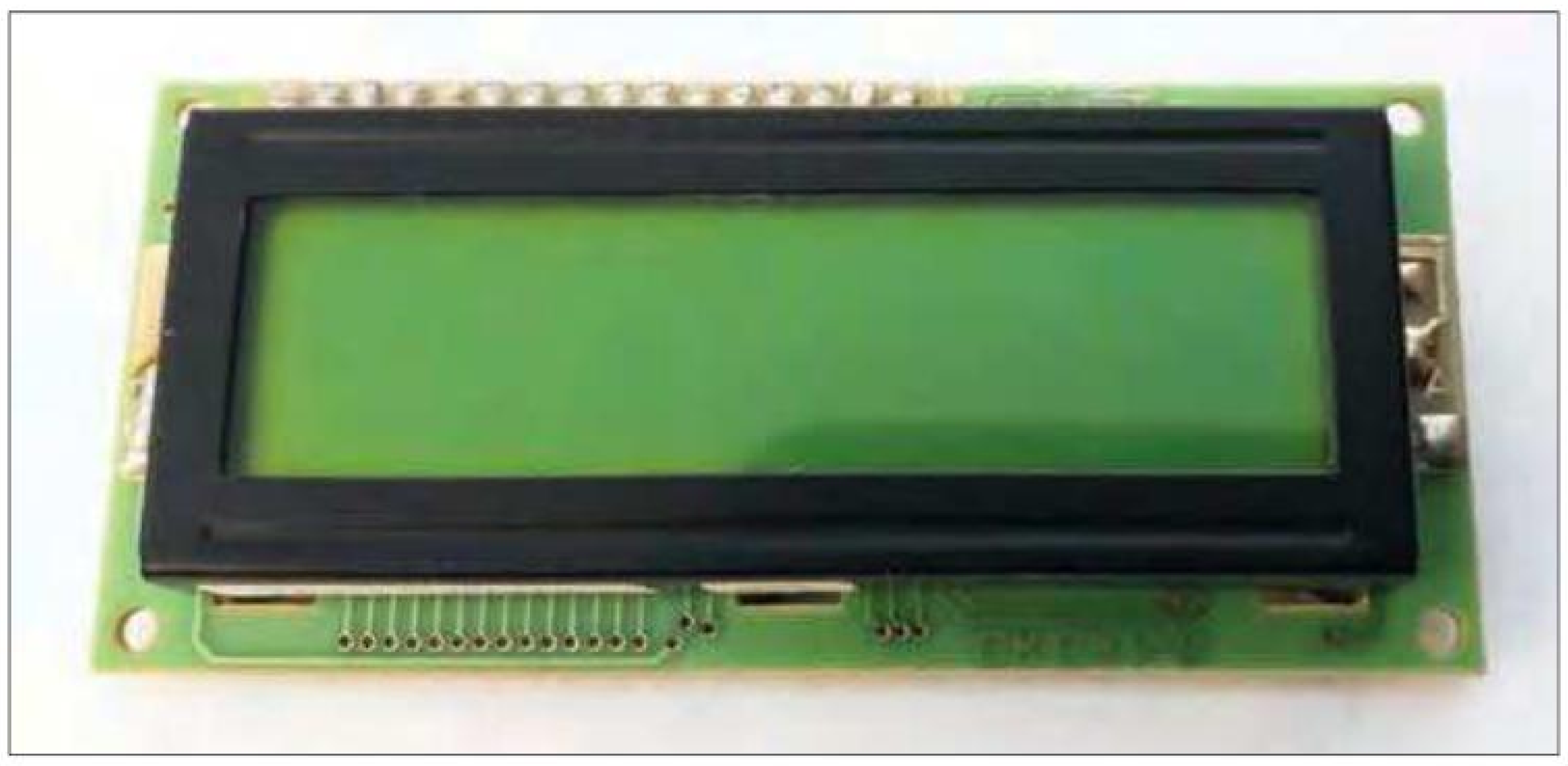


Fig.1. 2×16-character LCD.

There is one important part of that message that may change: the section `Content-Length`. Here, `23` is specifying how long the real payload of the HTTP message is. This information is required by the webserver so it can tell how many more data bytes will follow. And that brings us to the final part:

```
\r\n{\"SolarVolts\": %1.3f}
```

This is the actual message we are sending. Remember that this string is a format string for the `sprintf` C function, the `\"` characters will be replaced with a single `"` character, and the part `%1.3f` will be translated into a floating-point value, held in the variable `SolarVolts`, in the format `1.234`, or five characters. So, finally, the message we are sending to the website is:

```
{"SolarVolts": 1.234}
```

This has a `CRLF` sequence at the beginning. Add these characters up, and you will see they come to 23 bytes. The entire string is 180 bytes long, which matches the value specified in the `AT+CIPSEND` command.

Phew! That was a lot to take in, but the key point is that you can send a message with any variable name within the quoted string, and Thingsboard will create a new variable in the dashboard and save any data you send. Each time a message is received it is timestamped by Thingsboard before storing it in its database.

So now, if you decide that you are going to send a new variable of a different length, note the full length of the string, as shown above, and adjust the value specified in `Content-Length`, and the length specified in the `AT+CIPSEND` command.

As a final note, although we ran with the Thingsboard IoT platform, there are other free platforms available. We are currently evaluating **www.kaaiot.com/free-trial** after a recent demonstration by their development team. That service is provided for free if you have five or fewer devices, with historic data held for the previous three months.

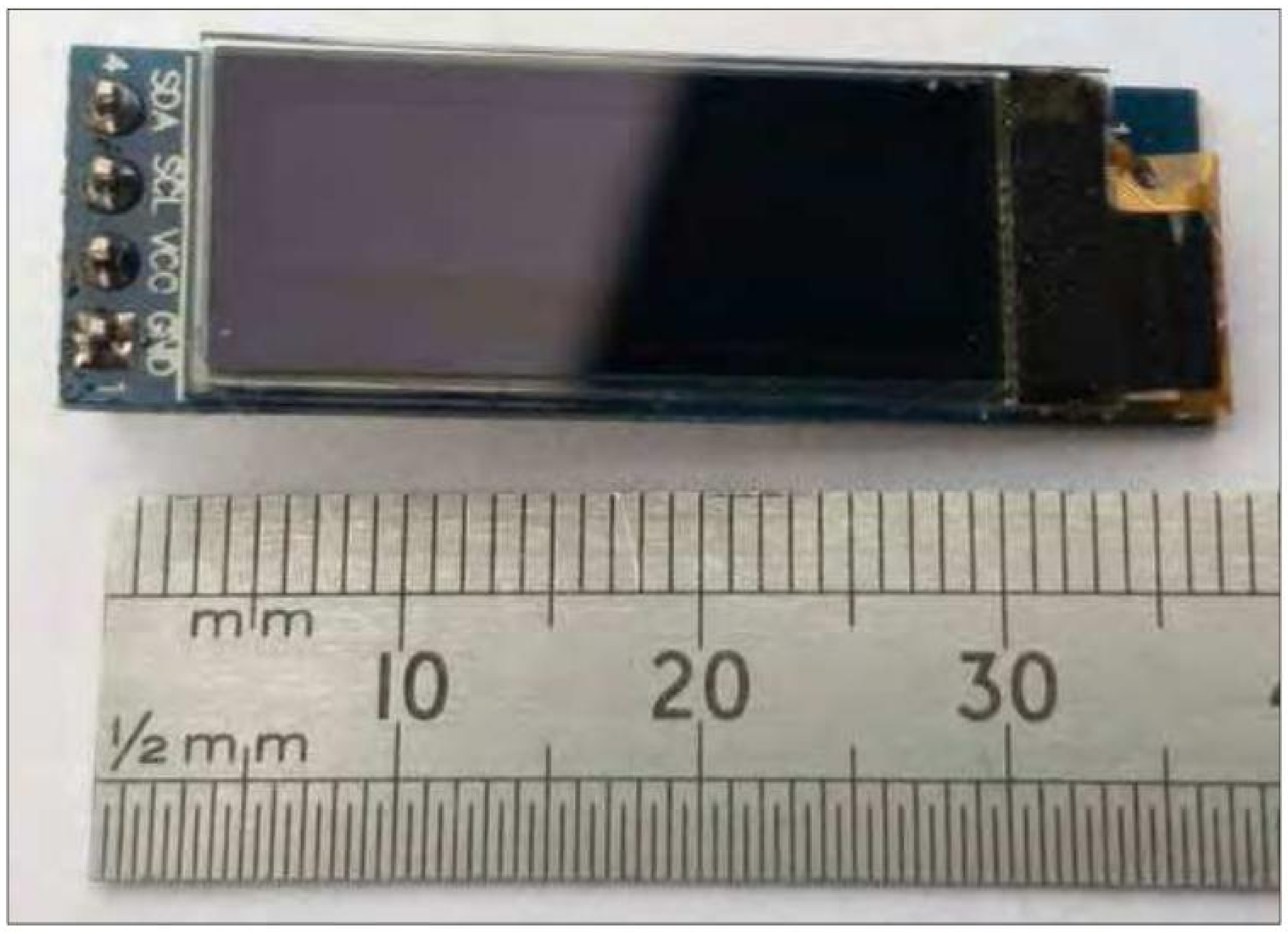


Fig.3. Tiny OLED screen.

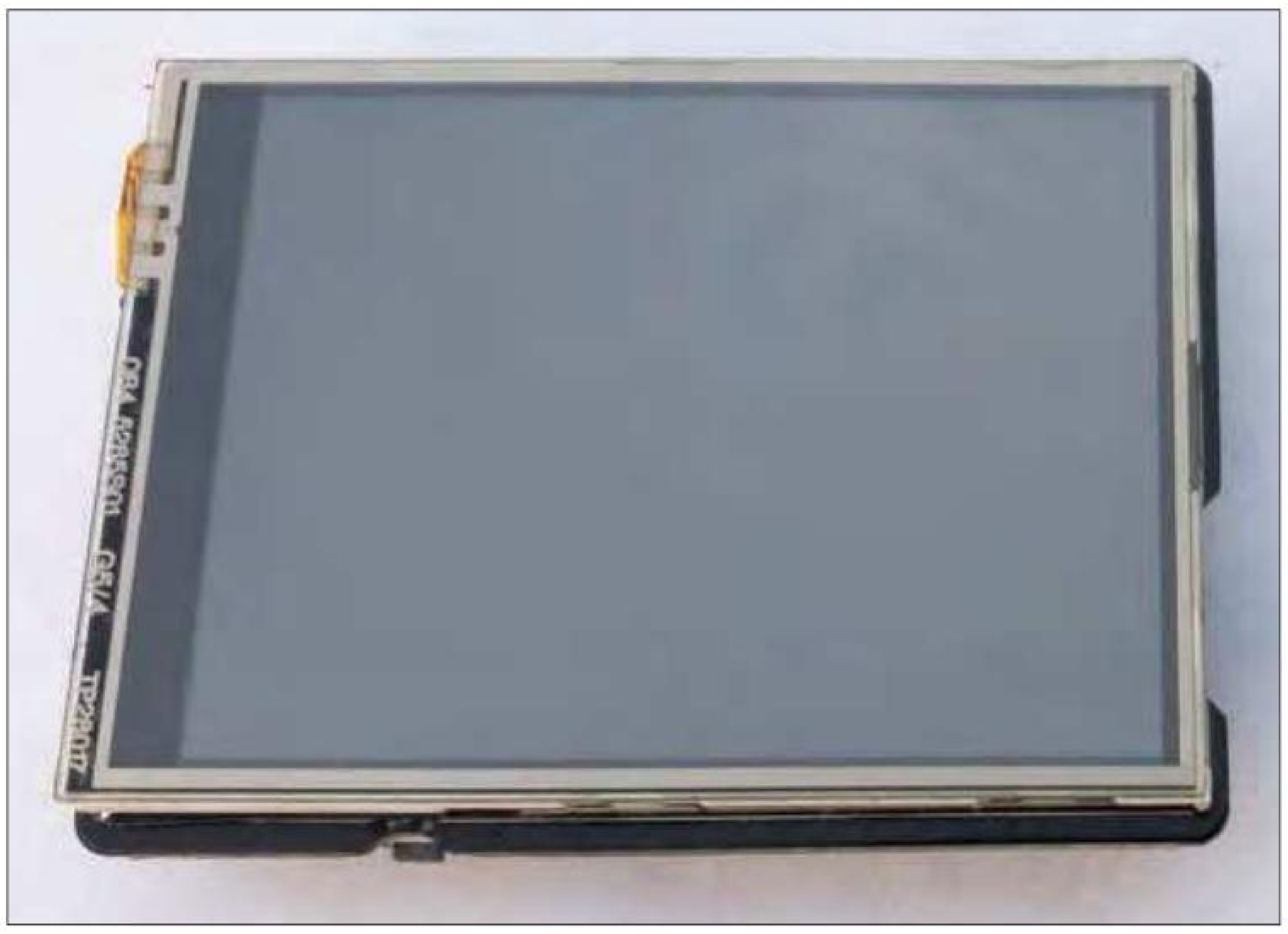


Fig.2. 320×240 colour graphics display.

Adding a display

It's time to move on from Internet connectivity to the next peripheral interface on our *Development Board* – the display. While this interface on HDR16 is labelled 'TOUCH LCD', it's not limited to a specific display technology, as we will see. The 12 GPIO pins allocated to this interface provide the flexibility to support a range of display technologies, albeit with some restrictions.

As recently as 15 years ago the choice of display technology to attach to a microcontroller was very limited – typically, the 2×16-character LCD panel, with a backlight if you were lucky. In those days, we were happy with this status quo as the predominate technology since before this were seven-segment LEDs which were large, power hungry and extremely limited.

Fast forward to today and, amusingly, the 2×16-character LCD is still popular and quite appropriate for many applications. However, there are several much more interesting options available, which provide full graphic capability and other interesting features. These can be summarised as follows.

2×16-character LCD

These require a few GPIOs to control them and can operate at 3.3V or 5V, depending on the model purchased. They are very simple to use, with multiple software drivers available on the Internet. The example shown in Fig.1 has an LED backlight.

Full-graphic displays

These panels are available in a range of physical sizes but have the added benefit of an integrated controller with memory that simplifies the interface to a resource-constrained microcontroller. The example shown in Fig.2. has an integrated

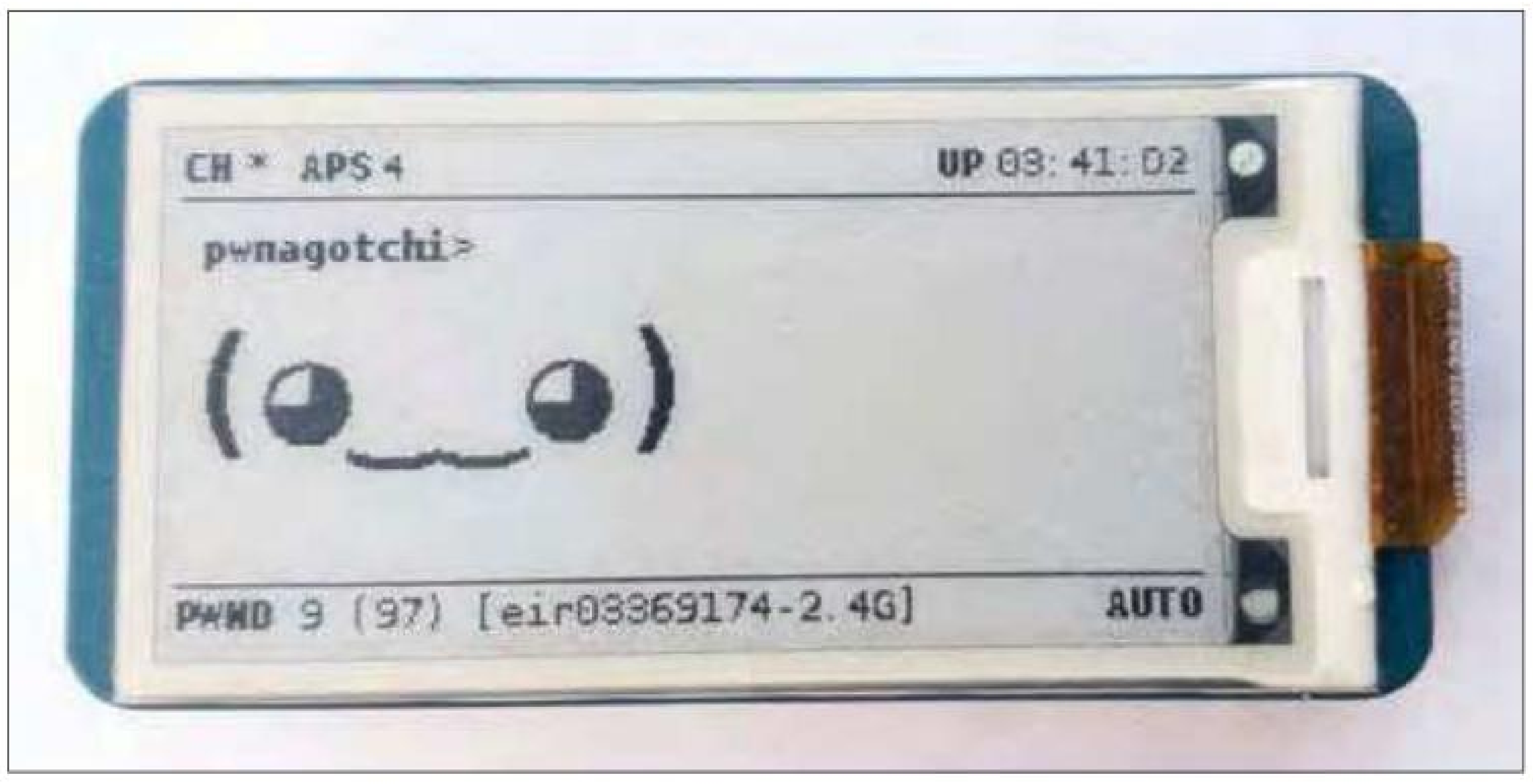


Fig.4. ePaper: a 'modern-day Etch A Sketch!'

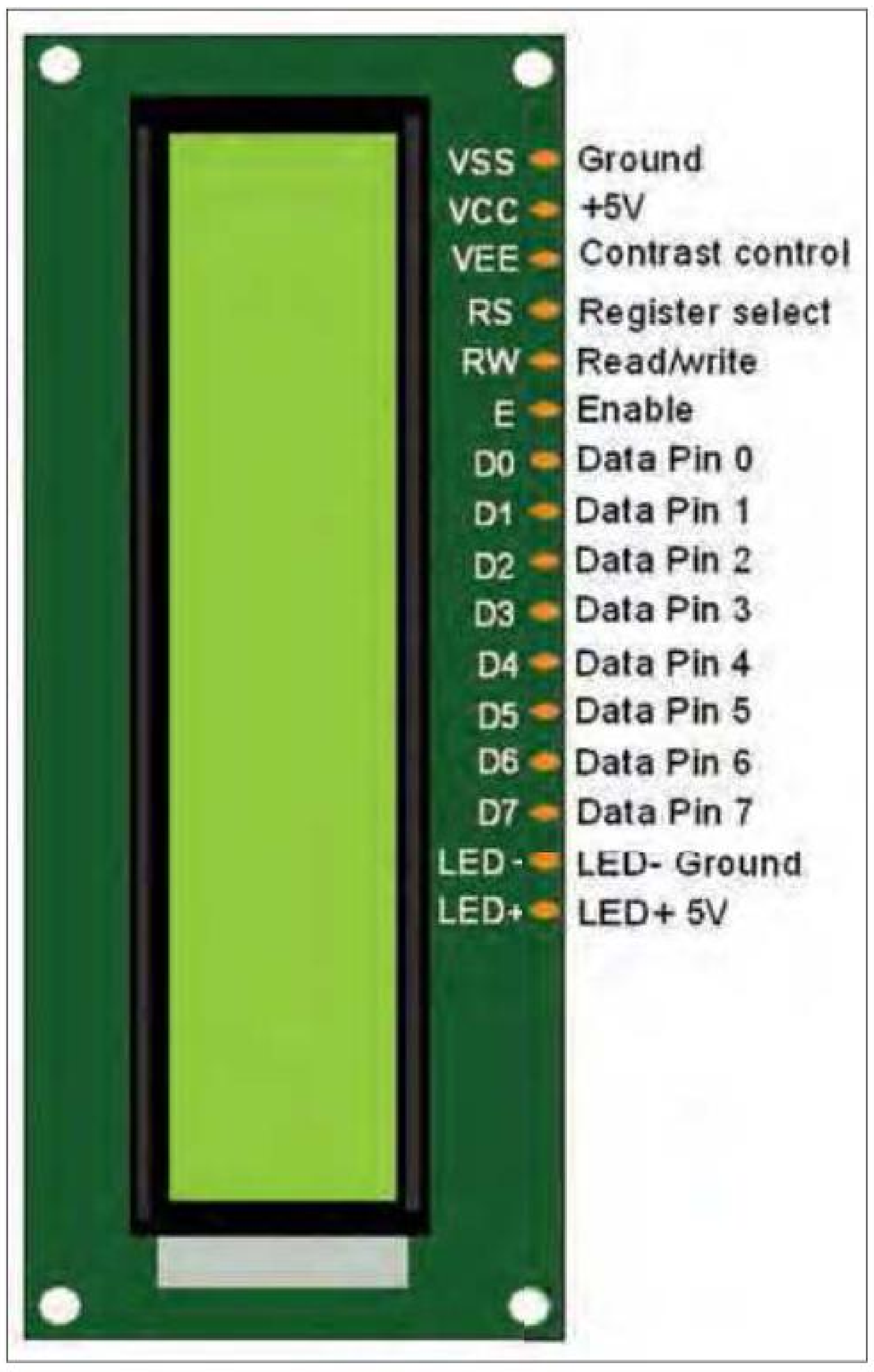

VSS Ground
VCC +5V
VEE Contrast control
RS Register select
RW Read/write
E Enable
D0 Data Pin 0
D1 Data Pin 1
D2 Data Pin 2
D3 Data Pin 3
D4 Data Pin 4
D5 Data Pin 5
D6 Data Pin 6
D7 Data Pin 7
LED- LED- Ground
LED+ LED+ 5V

Fig.5. 2×16-character LCD pin mapping.

resistive-touch sensitive layer, easily controlled by a microcontroller to enable rich interactive user interfaces. Resistive touch interfaces are not as nice as the capacitive touch sensors we are used to on mobile phones and tablets, but they are cheap and easy to interface to, and require just four G/O pins to control.

OLED

These are an interesting recent invention that provide high-resolution vibrant displays, in a thin physical format, with no need for an additional backlight. Due to their flexibility and low cost of manufacture they have become available in a wide range of sizes. Slightly more expensive than LCD panels, but their thin structure makes them eminently suitable for small and novel projects. Despite its tiny size, the display in Fig.3. has a resolution of 128×64 pixels.

ePaper

One of the most unusual display innovations to have occurred in recent years is ePaper technology. These are mainly monochrome displays that retain their image even when power is removed. They have excellent contrast ratio and high resolution, making them easy to read. The example shown in Fig.4. has been designed to work with the Raspberry Pi, but we can use it too. The drawback with these displays is that changing the image shown, even just a few pixels, requires a refresh that can take up to a second. For projects where information changes *infrequently*, these can be ideal due to their extremely low power requirements.

LVDS

Commonly used in laptops and high-end mobile phones, LVDS panels are so named due to the electrical interface used to communicate with them. (low-voltage differential signalling.) These panels can be large, high resolution and cheap, but unfortunately cannot be connected directly to a microcontroller. The communication speed is in the hundreds of MHz, and a huge RAM buffer is required to store the data to be displayed. Specialised processors such as the Raspberry Pi have a dedicated display driver peripheral and the ability to address a large RAM buffer, but not our humble PIC.

Let's take a few example displays and walk through the process of connecting them up and displaying data. We start with a classic.

2×16-character LCD

We first create a project in MPLAB, just as we did in the previous article, remembering to select our processor, the PIC18F47K42. We name this project **2x16lcd**

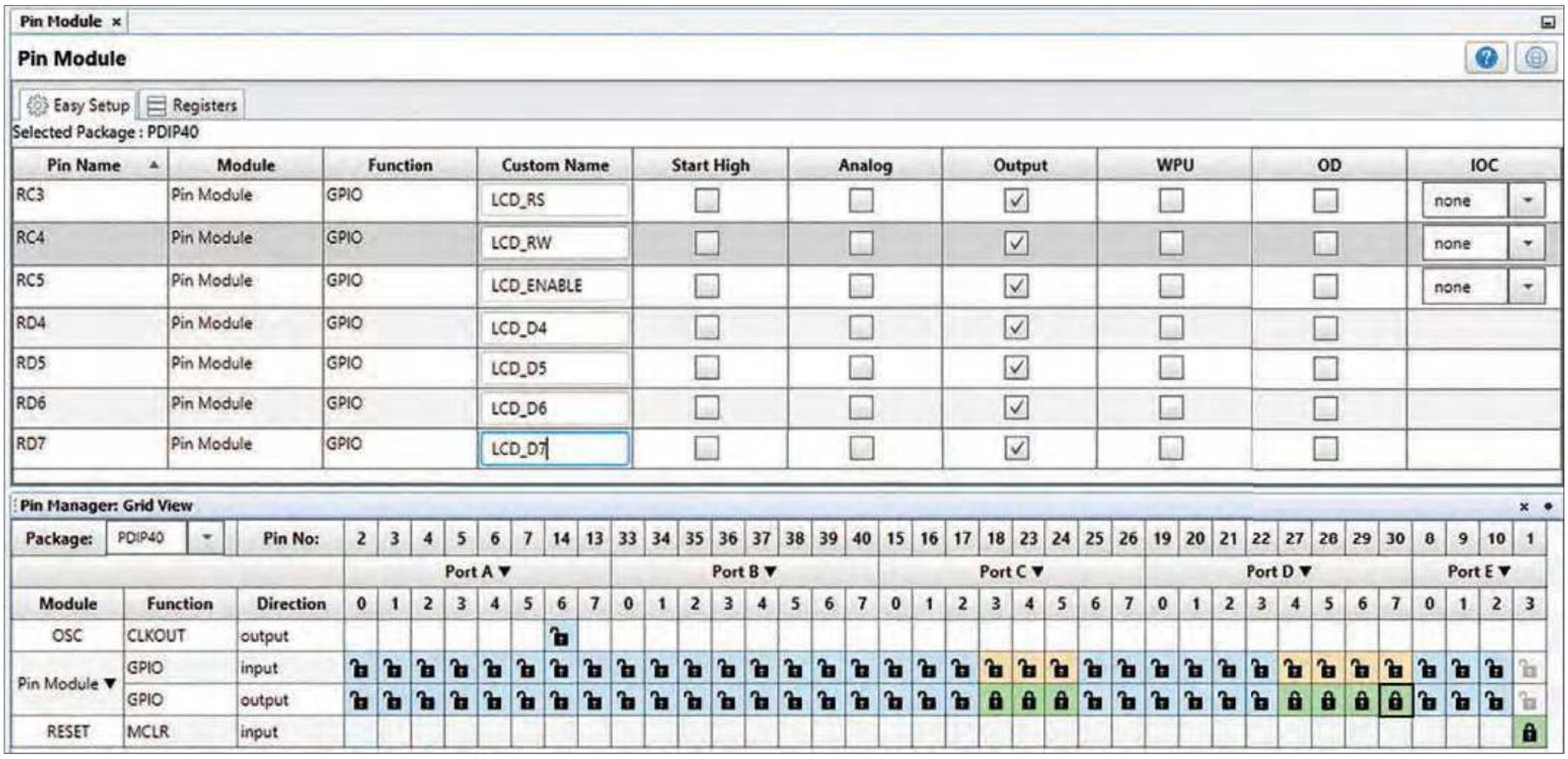
The initial project setup does not create any actual source files like **main.c**, but that is OK as we will use the MCC tool to configure some options, and it will create the initial source files for us.

Start by configuring within MCC the System Module peripheral, found in the 'Project Resource' window, to select our CPU clock source. Change 'Oscillator Select' from EXTOSC to HFINTOSC, 'HF Internal Clock' to 64_MHz, and 'Clock Divider' to 1. We will run the processor at its maximum speed of 64MHz.

Now for the GPIO pins. Click on the Pin Module of the Project Resource window, then locate the 'GPIO Output' row in the 'Pin Manager: Grid View' at the bottom of the window. Within this row, click on the lock icons for Port C 3,4,5 and then Port D 4,5,6,7.

Notice that as you click on each lock it turns green, and the pin name appears in a row at the top of the window. When done, change the 'Package:' field to 'PDIP40'.

Referring to Fig.5, there are three LCD control signals RS, R/W, ENABLE and then just four data pins required: D4, D5, D6 and D7 (the upper four pins of the data bus on the display must be used in 4-bit communication mode.) We will give meaningful names to our IO pins, renaming the 'Custom Name' column in the 'Pin Module' window for each pin to match its intended function. You can see this in Fig.6. Note that you must also unclick the analogue function associated with these pins.


Pin Module ×
Pin Module
Easy Setup
Registers

Selected Package : PDIP40

Pin Name ▲	Module	Function	Custom Name	Start High	Analog	Output	WPU	OD	IOC
RC3	Pin Module	GPIO	LCD_RS	☐	☐	☑	☐	☐	none
RC4	Pin Module	GPIO	LCD_RW	☐	☐	☑	☐	☐	none
RC5	Pin Module	GPIO	LCD_ENABLE	☐	☐	☑	☐	☐	none
RD4	Pin Module	GPIO	LCD_D4	☐	☐	☑	☐	☐	
RD5	Pin Module	GPIO	LCD_D5	☐	☐	☑	☐	☐	
RD6	Pin Module	GPIO	LCD_D6	☐	☐	☑	☐	☐	
RD7	Pin Module	GPIO	LCD_D7	☐	☐	☑	☐	☐	

Pin Manager: Grid View
Package: PDIP40
Pin No: 2 3 4 5 6 7 14 13 33 34 35 36 37 38 39 40 15 16 17 18 23 24 25 26 19 20 21 22 27 28 29 30 8 9 10 1
Port A ▼
Port B ▼
Port C ▼
Port D ▼
Port E ▼
Module
Function
Direction
0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3
OSC CLKOUT output
Pin Module ▼ GPIO input
GPIO output
RESET MCLR input

Fig.6. GPIO pin configuration in MCC.

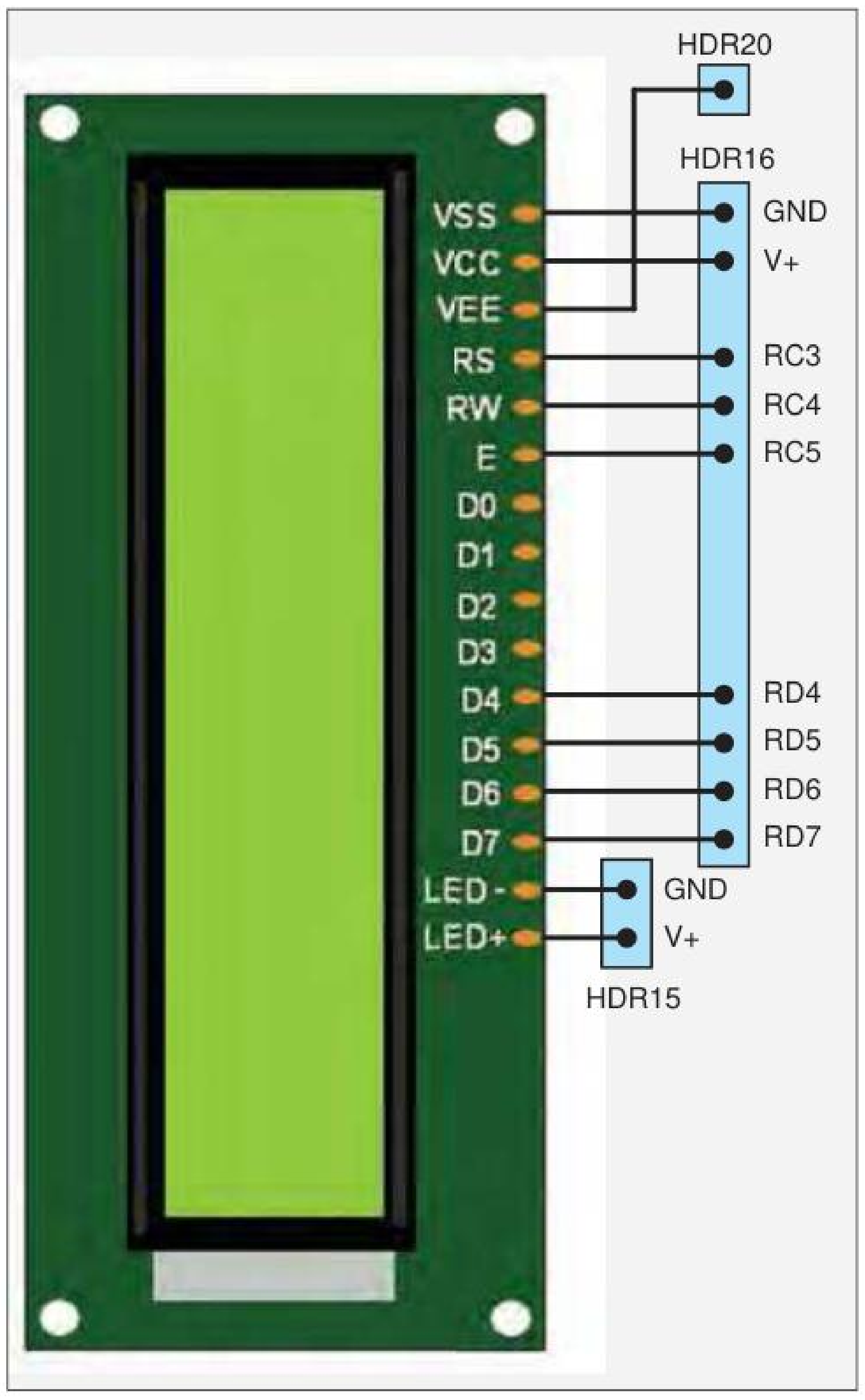


Fig.7. Hooking up the 2×16-character LCD to our board.

You can now click the 'Generate' button in the 'Project Resources' window to create our source files.

Now to create our LCD driver. To keep things tidy we will store each display's driver code in separate files, so we start by creating files **2x16lcd.c** and **2x16lcd.h** and adding them to the project.

In the 'Project' tab in the top left window, right-click over the 'Source Files' icon, select 'New' followed by 'main.c...'

In the 'File Name' field enter '2x16lcd' and click 'Finish'. The file will open in the IDE; delete the three lines defining an empty main function.

Now right-click over the 'Header Files' icon and select 'New' followed by 'xc8_header.h...'

In the 'File Name' field enter '2x16lcd' and click 'Finish'. Again, the file will open in the IDE. This file template has lots of complex comments, just go ahead and delete all the contents.

You can run a build at this point to confirm there are no errors, which if there are, will be minor typing mistakes on your part!

So, we now have our files, but how will we write our actual driver code? Thankfully, this display has been popular for decades so there are dozens if not hundreds of well-written examples provided for free on the Internet. Surprisingly, Microchip have not provided an MCC function for driving LCDs. They do, however, have a legacy library which we can use as the basis for our own driver. The library can be downloaded from the Microchip website which you can find if you search for 'PIC18F Legacy Peripheral Libraries v2.0'. There is no need to however, as we will take the source code we need and add it to our own source code, which we provide for download from the January 2022 page of the magazine website. You may find the full Microchip download useful however for other driver examples. While there are many sources available on the Internet, we preferred to go with an original Microchip driver as we know the files are free for re-use with no licence restrictions.

Listing 2. Using the 2×16-character LCD driver.

```
#include "mcc_generated_files/mcc.h"
#include "2x16lcd.h"

void main(void)
{
   // Initialize the device
   SYSTEM_Initialize();

   // Enable the LCD
   Open2x16LCD();

   // Turn blinking and cursor off
   WriteCmdXLCD(BLINK_CURSOR_OFF);

   putrsXLCD("Practical");
   WriteCmdXLCD(LINE_2_ADDRESS);
   putrsXLCD("Electronics");

   __delay_ms(2000);

   WriteCmdXLCD(CLEAR_SCREEN_CMD);

   putrsXLCD("Postcard PIC");
   WriteCmdXLCD(LINE_2_ADDRESS);
   putrsXLCD("Dev Board");

   while (1)
   {
      // Add your application code
   }
}
```

The downloaded library contains many libraries (all worth looking at) but we focus on the XLCD library, which supports just the 2×16-character LCD, based on a 44780 LCD controller (this controller IC has been copied numerous times by IC manufacturers and the chipset on your LCD may not say the same part number, but they are all compatible.) The library we are interested in is called 'XLCD'. This contains ten source files, which sounds intimidating until you discover that each file is a single function (a good design principle, but a bit of over-kill for a simple display.) After a quick review of each file, we can see that several files related to creating custom bitmaps and reading display memory can be ignored. All we want to do is initialise the display, clear it, set a cursor position and write characters to the display. This requires far less code (although it is nice to have the extended capabilities available.) We will copy all the functions we require into our driver file, **2x16lcd.c**

We start by copying across the display initialisation code. This sets all the I/O pins to correct defaults and sends a short configuration sequence to the display. Our initial task is to re-assign I/O pin defines to match our selection, and also implement some delay routines – the LCD's controller requires a short delay to execute each command.

Most of our effort was associated with writing the delay functions, important because the LCD's internal controller runs relatively slowly and needs time to complete commands sent to it.

With the delays implemented (thanks to messing around with an oscilloscope and checking timings) we can just copy over the required functions to make the 'open' function compile. With that working, the remaining functions can be copied over. Their prototypes are added to the **2x16lcd.h** header file, so we can reference the functions in our **main.c** file. The full **main.c** contents to drive the display can be seen in Listing 2.

To wire up the LCD, follow the schematic shown in Fig.7. Note that this display runs at 5V (you can find 3.3V versions, but they are more expensive.) Because of this, we must remove the SD Media card interface and ESP-01 module as these operate at 3.3V only. These LCDs require a variable resistor to adjust the contrast, but we can make use of one already fitted to the *Development Board*. You can see an example setup and display output in Fig.8.

It's worth noting that these 2×16-character LCDs come in a variety of styles, 3.3V operation, plus a choice of interface: parallel, I²C and even UART.

Full-colour graphic

Let's move to the opposite end of the spectrum and interface a popular full-graphic display, the 1.8TFT SPI 128*160 module. This is a small 1.8-inch diagonal display that has a standard controller IC fitted, the ST7735. This IC has a 48KB internal full-frame RAM buffer and provides an SPI bus for control, so it can be coupled with a very constrained microcontroller. It's manufactured by many vendors, so is unlikely to become unavailable at short notice.

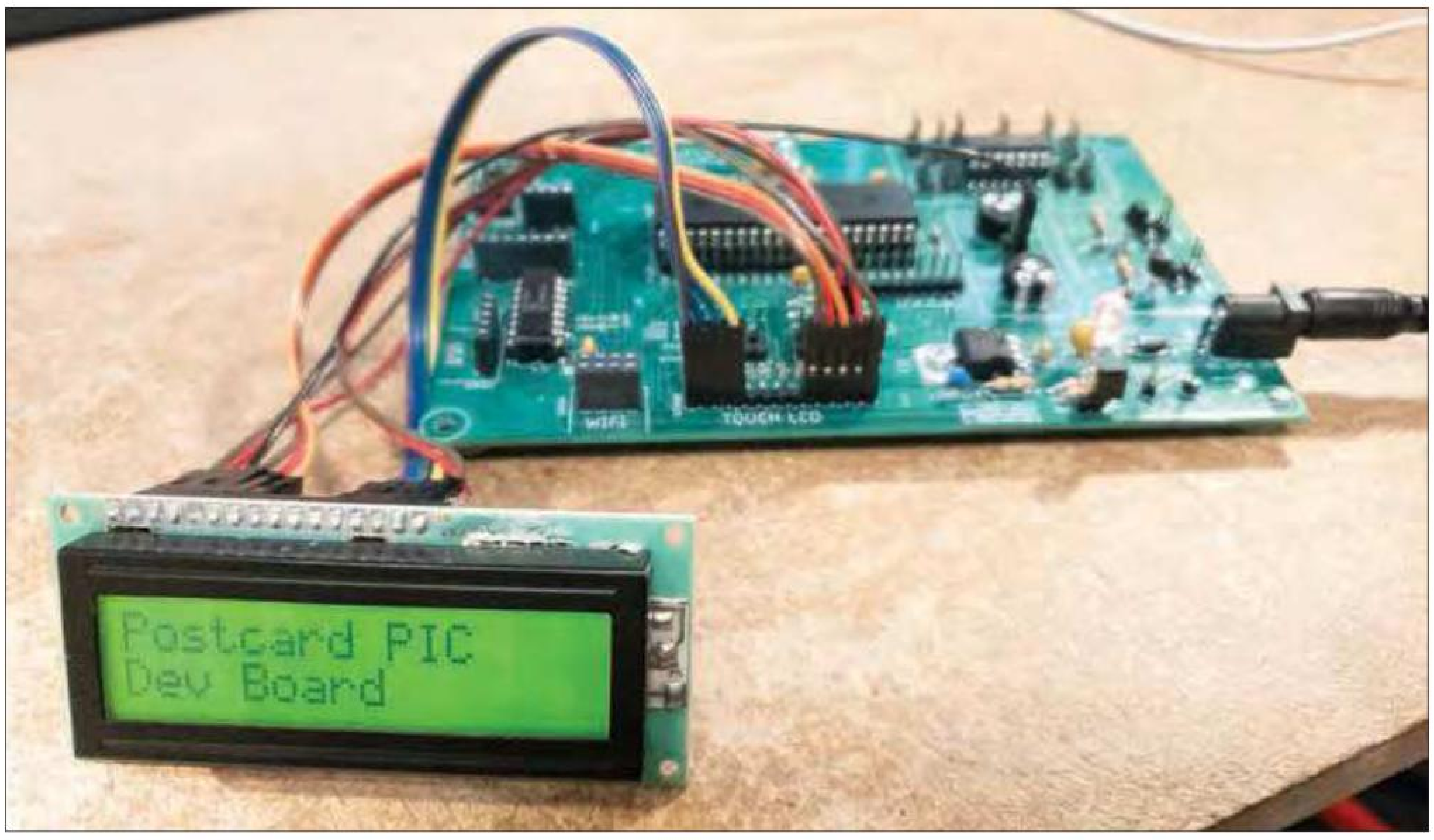


Fig.8. The 2×16-character LCD in action.

The interface to this display is very simple: 3.3V DC, an 'SPI-like' interface using just the clock signal and data input, and three control signals. You can see the display in Fig.9, and the wiring to our board in Fig.10. Because this display is based on TFT technology there is no need for a contrast adjustment resistor.

The software interface to this display is very basic – you can set and clear individual pixels, and not much else. High-level functions, such as drawing lines, circles and even text must be built up from simple pixel functions. As you can guess, there is a complex software requirement coming!

Let's go ahead and create a project to drive the display. We start a completely new project, naming it `graphicLCD`. Once again, we start the MCC tool and set the processor clock to 64MHz, and the package type to PDIP40.

We are going to need the SPI peripheral, so we click on the '+' icon next to SPI1 in the 'Device Resources' list to add it to our device resources. In the 'Pin Manager: Grid View' tab, you can see three SPI function pins have been added to the list, and Port C pins 3 and 4 have been automatically added as SCK and SDI signals. We can move these to other pins if we want, but doing so requires messing with peripheral port select registers. That's unnecessary anyway as these two pins come out to our LCD header (yes, we thought ahead when designing the *Development Board's* pin allocations!) On the 'SDO1' row, click on the lock icon under Port C pin 5 to select that as the SPI bus output pin.

We now want to add our three control signals, RA5, 6 and 7. In the 'Pin Manager: Grid View' tab on the 'GPIO Output' row, click on the icons for those three pins. Again, unclick the 'Analog' tick boxes for these three pins. We will leave the custom name associated with them unchanged.

That's all the configuration we need to do in MCC, so in the 'Project Resources' tab press the 'Generate' button to have MCC create our files.

Graphics driver

As mentioned, this display uses a common LCD controller IC called the ST7735S and driver software for this is freely available widely on the web – but finding the correct software can be a bit hit and miss. Thankfully, we developed a driver for this display back in 2014 when we launched the 'LPLC' Kickstarter, a board that also used a PIC18F processor. We can copy those files into our project and hopefully make just a few changes to reflect the different IO pins used. There are three source files:

```
LCD-Graphic-Font.h
LCD-Graphic-ST7735S.c
LCD-Graphic-ST7735S.h
```

To make use of these files the first step is to copy them into the project directory (in the same location as **main.c**). Next, we have to tell MPLAB to include these files within our project.

Click on the 'Projects' tab in the top left window of MPLAB to show a summary list of the files. Next, right-click on the 'Header Files' section in the tree list, then 'Add Existing Item...' Click on the **LCD-Graphic-Font.h** file, then click the 'Select' button. Repeat for **LCD-Graphic-ST7735S.h**. Now right-click on the 'Source Files' section, then 'Add Existing Item...' Click on the **LCD-Graphic-Font.c** file, then click the 'Select' button.

As this is the first time we have integrated this LCD driver software into one of our *Development Board* projects, we will have to make a few changes to the source files. This consists of changing the I/O pins for the three control signals, and using the MCC-generated functions for writing to the SPI peripheral. And nothing else. In your own projects you may need to adjust the 'Clock Divider' field of the SPI1 peripheral to get proper operation, since long wires connecting to the display will limit how fast the bus can run for reliable operation. On our setup we run the SPI bus at 6.4MHz with 20cm hookup wires connecting the display; you should be able to run this at 10MHz or more with very short wiring.

We created a very simple program within our project's **main.c** file to test some of the functions. You can see the results of the program shown in Listing 3 in the screen shot shown in Fig.11.

Fig.9. 1.8-inch graphics LCD.

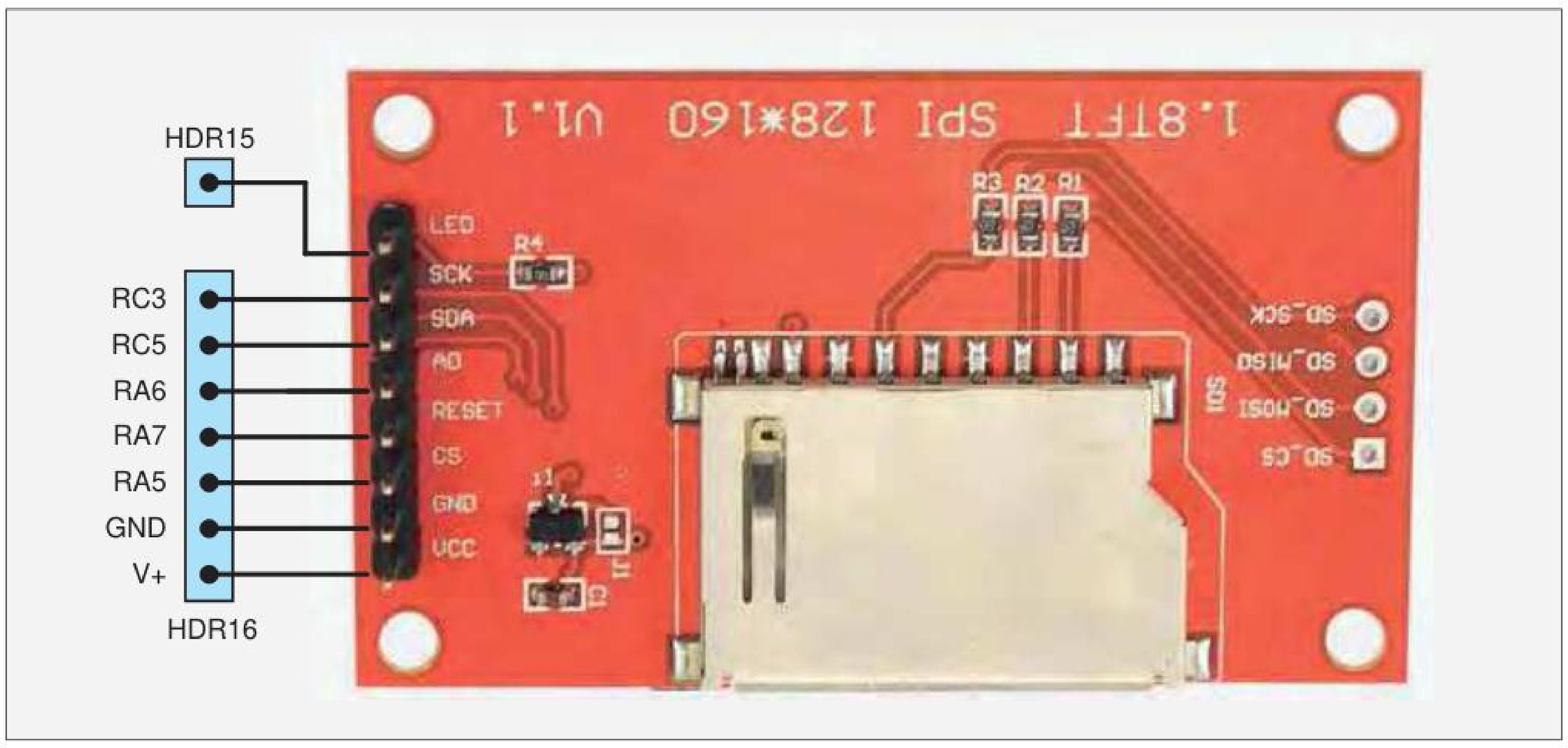


Fig.10. Wiring schematic for the graphics display.

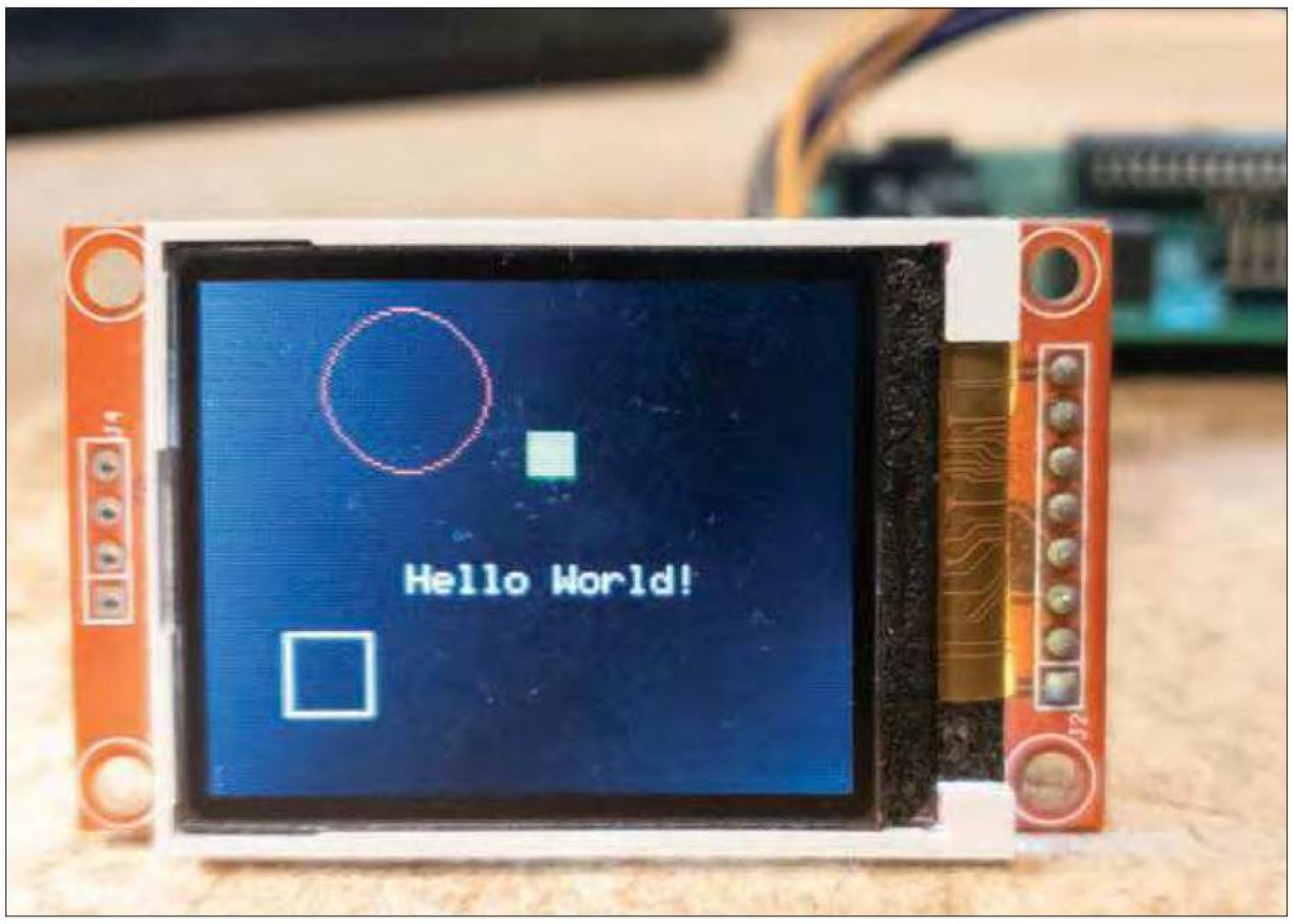


Fig.11. The 1.8-inch graphics LCD in action.

Listing 3. Using the full graphic display.

```
#include "mcc_generated_files/mcc.h"
#include "LCD-Graphic-ST7735S.h"

void main(void)
{
   // Initialize the device
   SYSTEM_Initialize();

   SPI1_Open(SPI1_DEFAULT);
   LCDST7735sInit();

   LCD_Clear(BLACK);

   LCD_ShowString(50,50,"Hello World!");

   LCD_DrawRectangle(20, 20, 40, 40);
   POINT_COLOR = RED;
   Draw_Circle(100,50,20);
   LCD_Fill(80, 80, 90, 90, GREEN);

   while (1)
   {
     // Add your application code
   }
}
```

If you like the format of this display, you can find similar display modules available across the Internet. At the time of writing, this version which should be compatible is available from **eBay.co.uk** as part number 174564132213.

All these steps to incorporate source files and configure MPLAB have been completed in the source files available on the magazine website, so you do not need to run through the steps above. The source files for both of this month's projects can be found on January 2022 page of the the magazine website in the zip file named **jan-2022-picnmix.zip**

We hope you have enjoyed this introduction to the use of the *PIC18F Development Board*, and have learned how to make use of MPLAB and the MCC tool to easily develop applications of your own.

We look forward to developing new projects from this platform in the future, and as always, if you have suggestions for projects, please send them in!

PIC n' Mix files

The programming files discussed in this article are available for download from the *PE* website.

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This CD-ROM version of the exciting and popular *Teach-In 8* series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. *Teach-In 8* provides a one-stop source of ideas and practical information.

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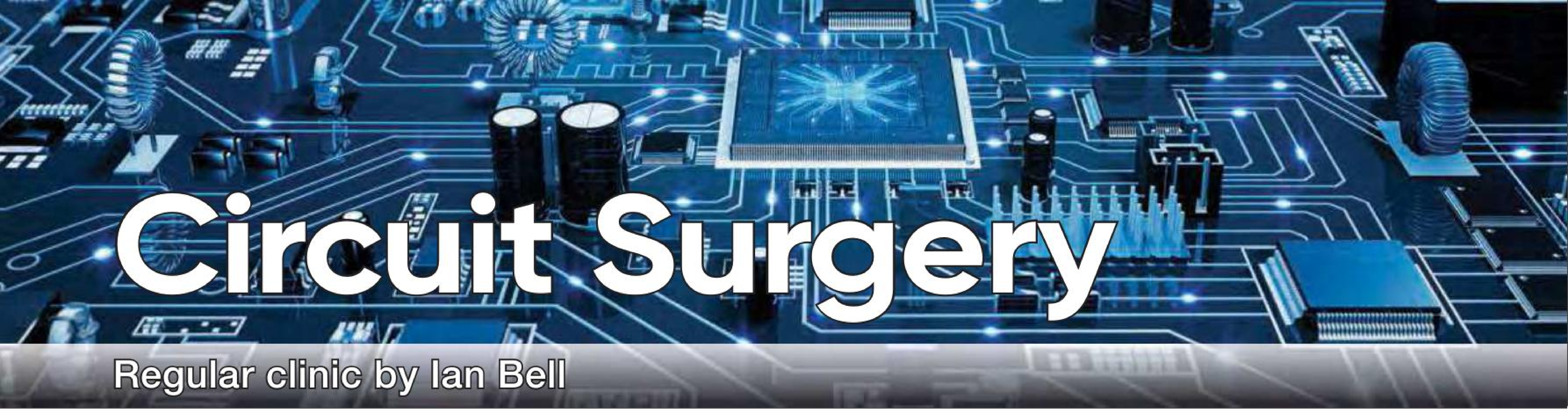


Circuit Surgery

Regular clinic by Ian Bell

Op Amp Logarithmic and Exponential Amplifiers – Part 2

Last month, we started to look at op amp-based logarithmic and exponential (also called antilog) amplifiers, focusing on logarithmic circuits. This month it is the turn of exponential amplifiers.

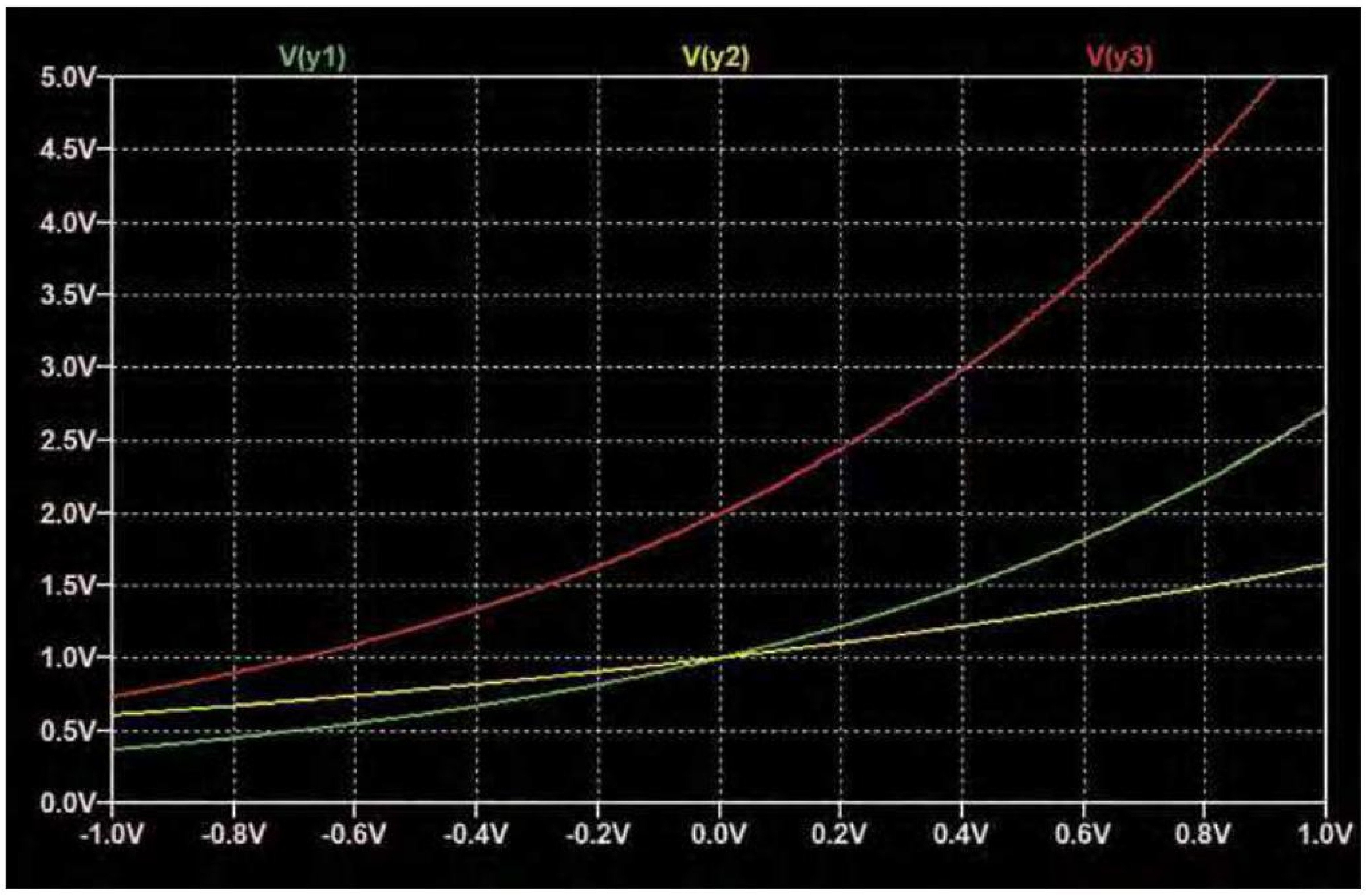


Fig.1. Ideal exponential or antilog input-output relationships: unscaled (y1, green, input scaled by 0.5 (y2, yellow) and output scaled by 2.

Raised to the power

Exponentials are the opposite of logarithms (inverse function), hence the term ‘antilog’. ‘Exponentiation’ means one number to the power of another, for example, x to the power y (x^y). As noted last month, for base 10 logarithms, if $y = \log_{10}(x)$ then we can find x from y using $x = 10^y$, that is 10 to the power y. Natural logarithms use base e, where $e = 2.71828$ (approximately). The ‘exponential function’ means e^a, so if:

$$y = \ln(x) \text{ then } x = e^y = \exp(y)$$

We also noted that we can easily convert between logarithm bases using a scaling factor, for example:

$$\log_{10}(x) = \ln(x) / \ln(10) \approx \ln(x) / 2.303.$$

This is useful because we might need a $\log_{10}$ function from a circuit, but log and antilog amplifiers are inherently based on the natural exponential (base e) relationship between the forward voltage of a PN junction (diode) and the current through it. For the antilog function we have:

$$a^n = e^{(n\ln(a))}$$

So, we can use a circuit based on the PN junction exponential function to obtain an output related to exponentiation of any number (within reason), for example: 2^n or 10^n.

Analogue synthesisers

As mentioned last month, exponential amplifiers can be used in multiplier circuits to convert the addition of logarithms to the final results, but this is not necessarily the best implementation of multiplication. Exponential amplifiers probably have a smaller range of uses than logarithmic amplifiers, but one interesting example is in analogue music synthesisers. In fact, these articles were originally inspired by the use of exponential amplifiers in the *MIDI Ultimate Synthesiser* project, which concluded in July 2019.

In the *MIDI Ultimate*, and similar designs, a linear control voltage is used to set the frequency of the note to be played. The frequencies of notes on a musical scale form a geometric progression, that is, each frequency is found by multiplying the previous one by a fixed value (or divided to find the previous one). This requires a fixed reference frequency (f_0), typically 440Hz (A above middle C). If the multiplying factor is a, then the next notes are af_0, a^2f_0, a^3f_0 and so on. In general, the n-th note up from the reference is a^nf_0. The control voltage for the synthesiser represents n, so we need to convert this to an to get a value proportional to the frequency. Given that the Western music scale has twelve notes (semitones) for each doubling of frequency (octave) we need:

$$a = 2^{(1/12)} \approx 1.05946\text{, so that } a^{12} = 2$$

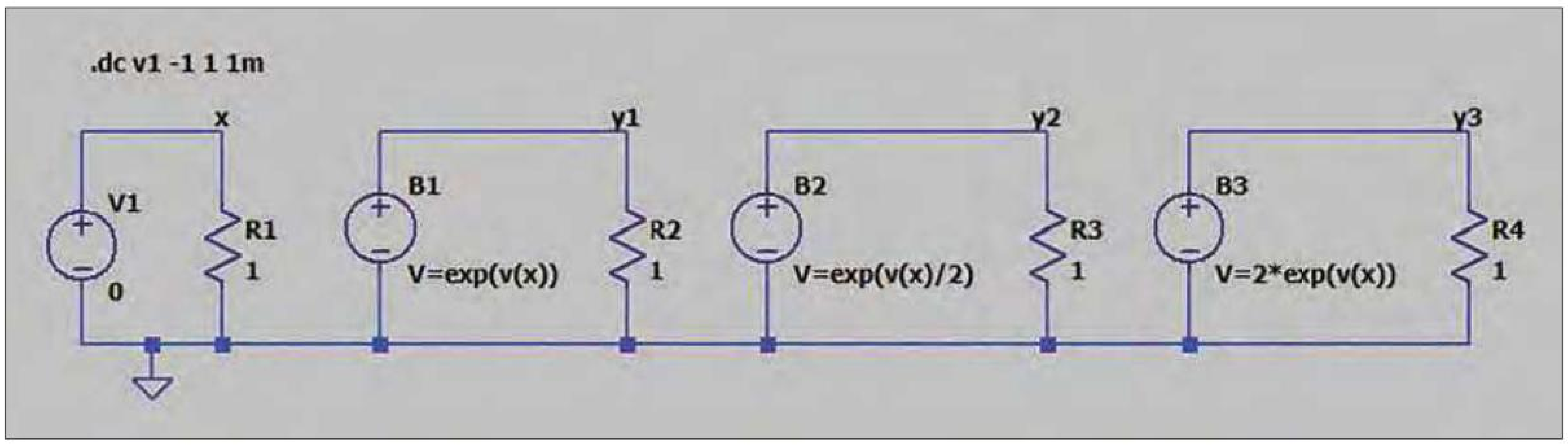


Fig.2. LTspice schematic for plotting Fig.1

The equation above shows that we can obtain the required input-output relationship for the synthesiser with an exponential amplifier based on a PN junction response, with suitable scaling.

Exponential functions

As we did with the logarithmic amplifier, we will start by looking at the exponential function itself. Fig.1 shows three responses of ideal exponential amplifiers to input voltage x, where:

$y_1 = \exp(x)$
$y_2 = \exp(x/2)$
$y_3 = 2*\exp(x)$

As with the idealised logarithmic curves last month, these graphs were produced using LTspice behavioural voltage sources and a DC sweep simulation, as shown in Fig.2. These curves represent mathematical (idealised circuit) functions rather than real circuit responses. The shape of these curves illustrates the general behaviour of an exponential response. As input amplitude increases, the effect of further increases becomes greater. The rate of increase increases with increasing input – it follows that the input/output curve is flat for small inputs and very steep for large inputs.

If we do not scale the output, then all the curves pass through 1 for zero input ($x = 0$) see y_1 and y_2 in Fig.1. This is because for any number n (other than zero), $n^0 = 1$, so $\exp(0) = e^0 = 1$. Scaling the output by n means that the output equals n for an input of 0 (see y_3 in Fig.2). Scaling the input down (see y_2 in Fig.2) results in a slower rate of change (and vice versa) – this changes the effective number base of the exponentiation.

Use and misuse

The fact that viral infections can increase exponentially has perhaps increased awareness of the term 'exponential' during the COVID-19 pandemic, but it is often misused (or misunderstood) to simply mean increasing rapidly, rather than the correct description of situations where *the rate of change is proportional to the quantity itself*. Observations of exponential phenomenon may show slow changes if the flatter, slower, growth part of the function is applicable – eventually the rate will increase significantly, but in some situations, this may not be observed.

Pure exponential functions will eventually produce extremely large numbers, but in real systems exponential phenomenon will reach some form of physical limit beyond which further increase is not possible. In the case of a virus (with no immunisation) the growth will stop when the entire population is infected. In the case of exponential amplifiers, the supply voltage or other circuit limitation will determine the maximum output value. Fig.3 shows another exponential function plotted on the same axes as Fig.1, this is $y = 1.0\times10^{-23}\exp(100x)$. With the given input range this function produces a very large output range, unlike the examples plotted in Fig.1. With $x = 1$ this function gives $y = 2.7 \times 10^{23}$.

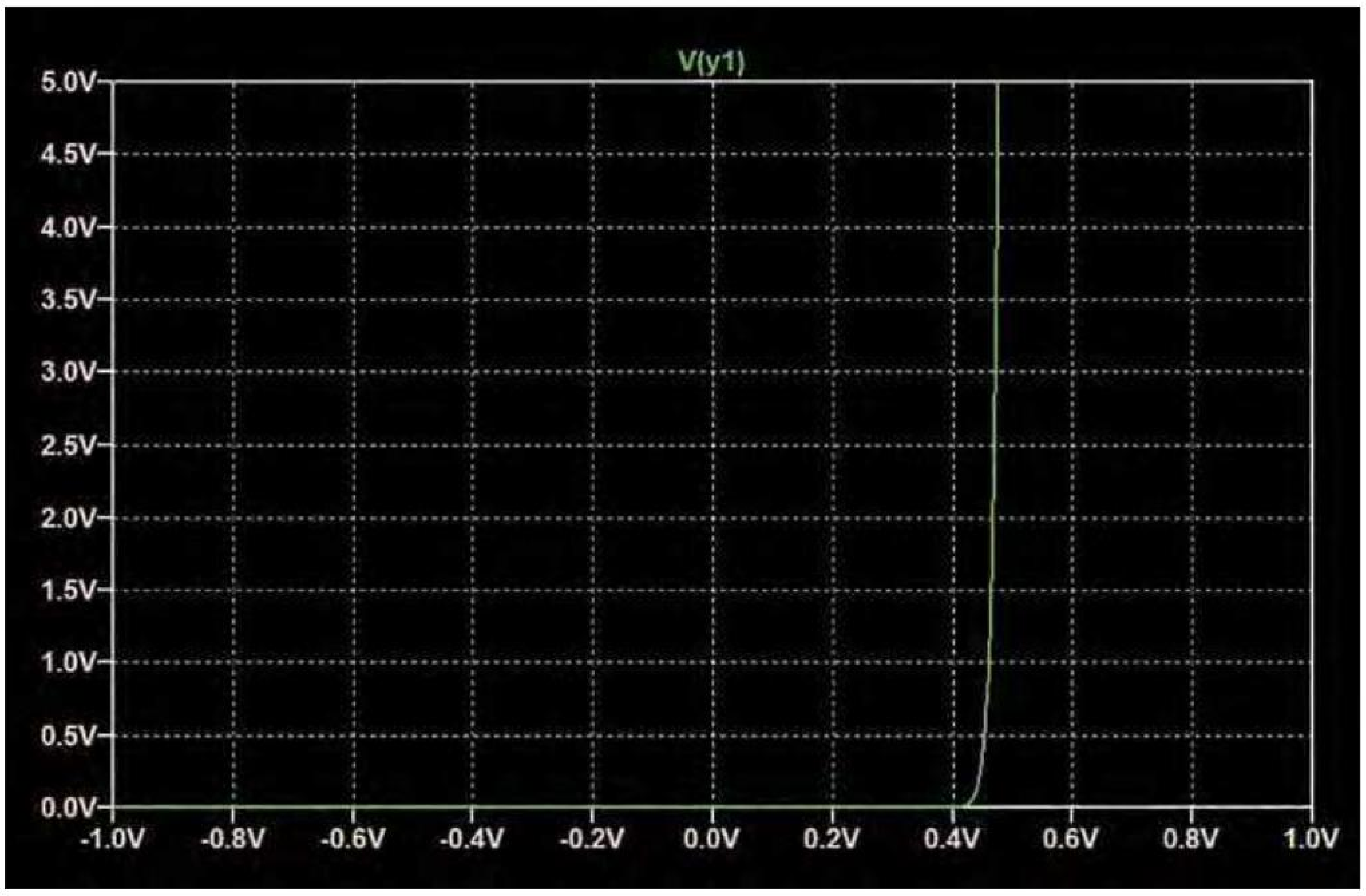


Fig.3. Depending on the range of observation relative to function behaviour, exponentiation can show relatively slow (Fig.1) or extremely rapid change (this example).

Diode equation

As mentioned above, exponential amplifiers can be based on the exponential current-voltage relationship of the diode, which is:

$$I_D = I_S\left[\exp\left(\frac{V_D}{V_T}\right) - 1\right]$$

Here, V_D is the voltage across the diode and I_D is the current through it. I_S is the diode saturation current – a parameter specific to the particular diode or transistor. V_T is the thermal voltage (defined last month). This version of the equation includes the –1 term, which is often left out to give a simplified version of the equation that applies to relatively large forward voltages. This fuller equation also applies to small forward and reverse voltages. Given that we know $\exp(0) = 1$, the –1 term ensures that $I_D = 0$ for $V_D = 0$. In terms of an exponential amplifier response, the –1 term will result in an output level shift (offset) in comparison with the basic exponential response.

Exponential amplifier

We can obtain a current which is exponentially related to an applied voltage simply by applying the voltage to a diode. This can be converted to a voltage by applying the current to a transimpedance amplifier (one with an input of current and output of voltage). Such a circuit is shown in Fig.4, in which the op amp and resistor form a transimpedance amplifier with gain R (V/A, volts per amp).

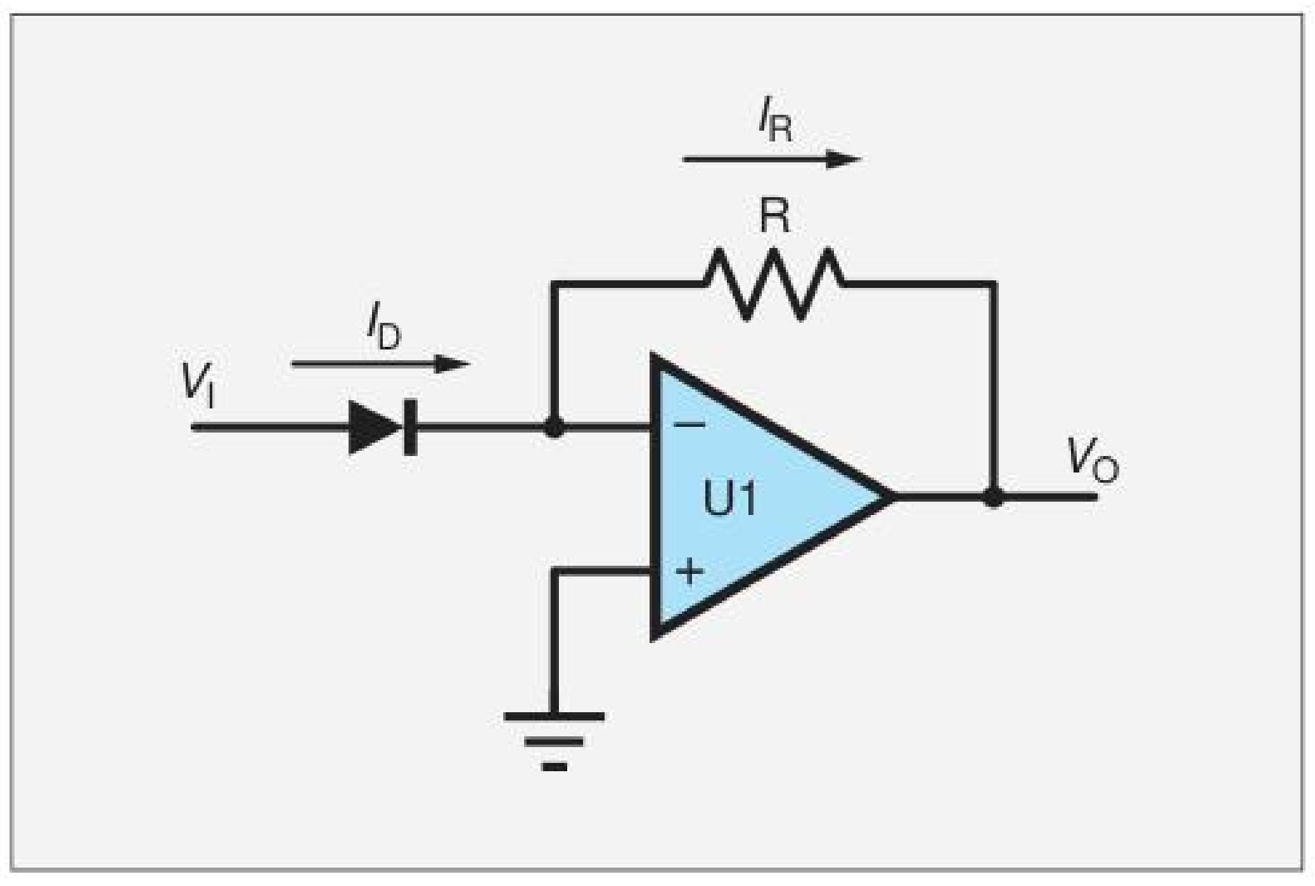


Fig.4. Exponential voltage amplifier based on a diode and op amp.

For the circuit in Fig.4, like the logarithmic amplifier discussed last month, the op amp's inverting input acts as a virtual earth, so the input voltage is effectively applied as the voltage across the diode, that is $V_I = V_D$. I_D is given by the diode equation above. The resistor is connected between the output and virtual earth, so the voltage across it is equal to the output voltage (V_O) and from Ohm's law the current is $I_R = -V_O/R$.

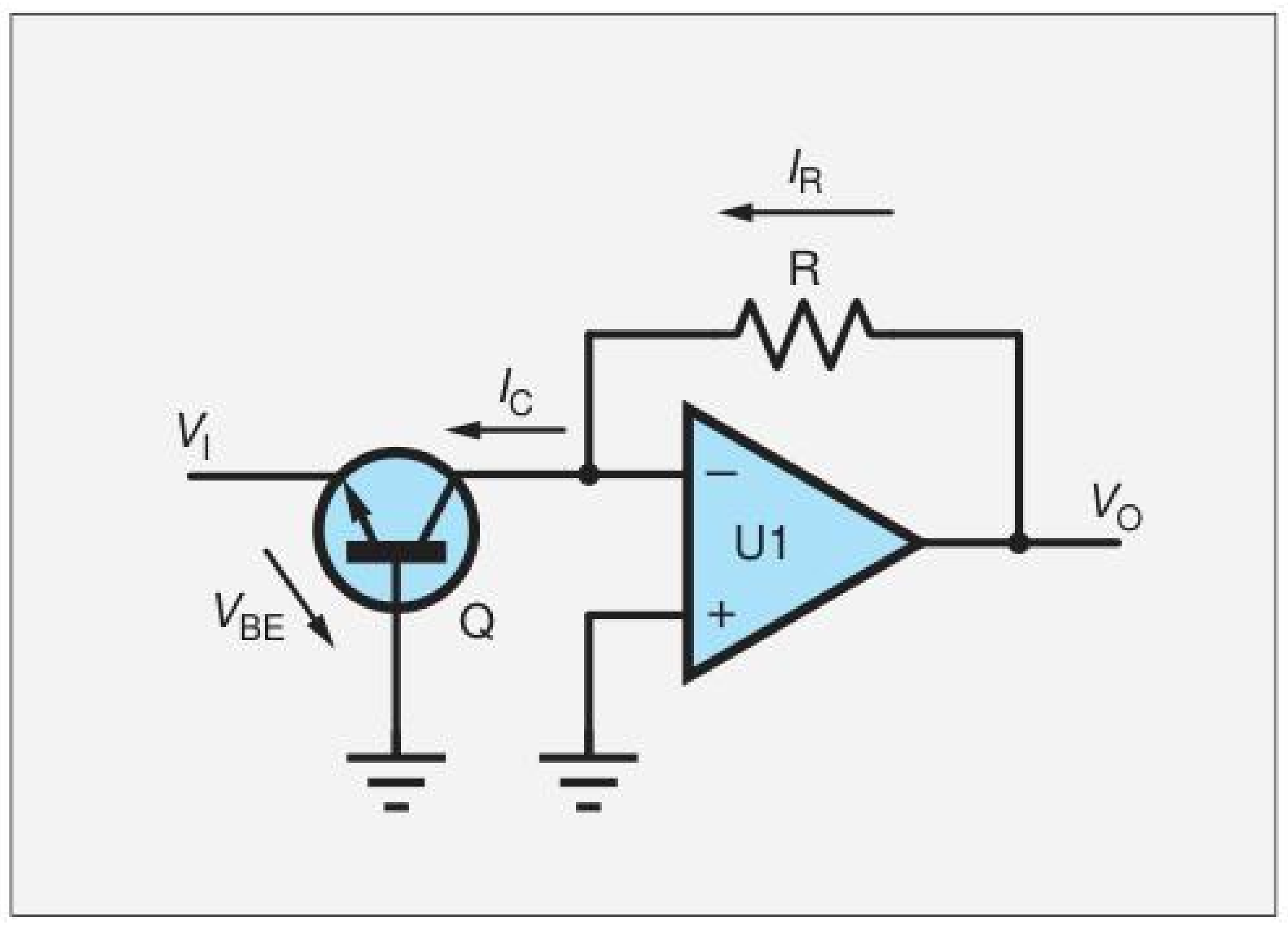
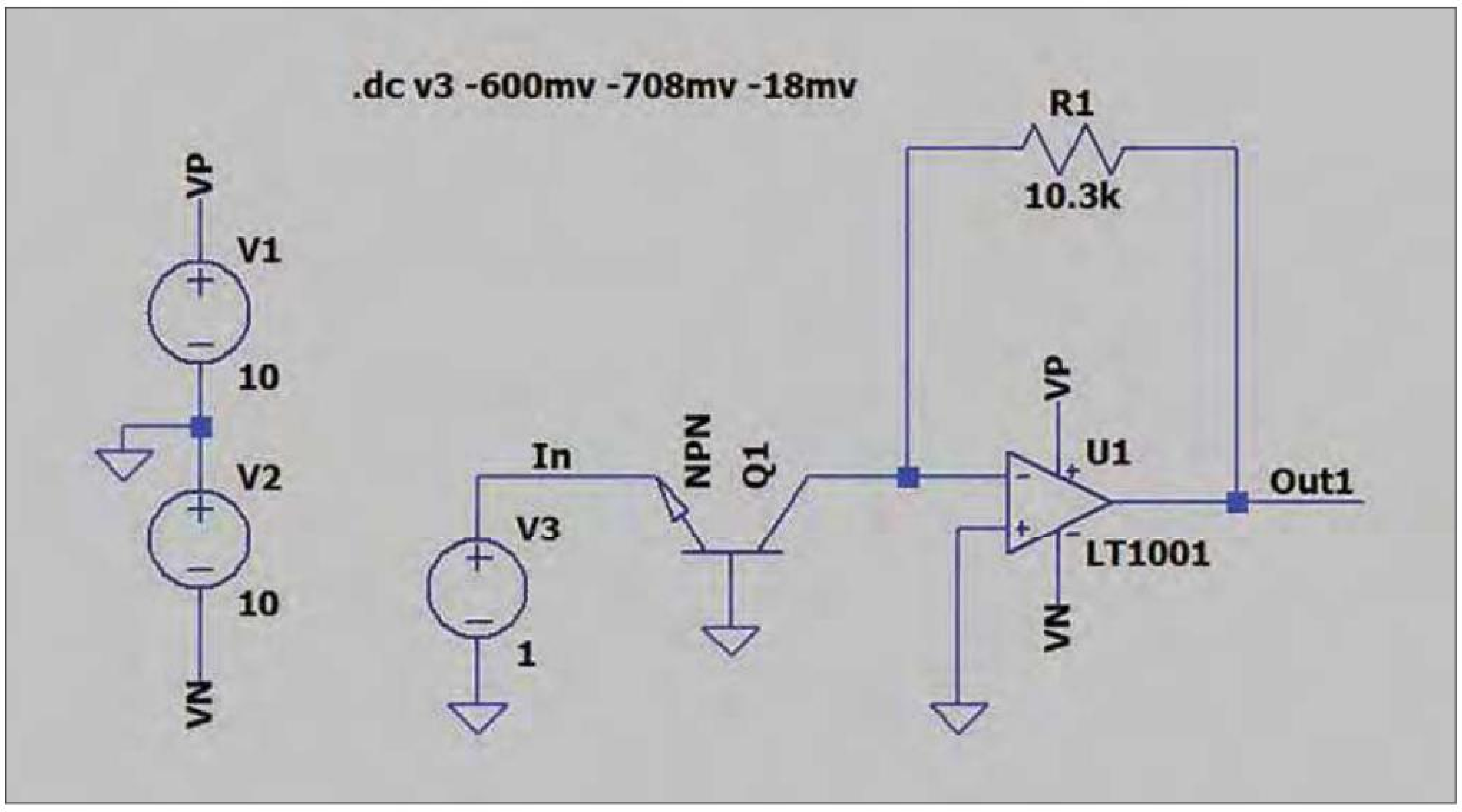


Fig.5. Exponential voltage amplifier based on a bipolar transistor and op amp.



```
.dc v3 -600mv -708mv -18mv
```

Fig.6. LTspice simulation schematic of the circuit in Fig.5, set up to illustrate doubling of the output for an 18mV input change.

Assuming an ideal op amp, no current will flow into the op amp's inputs (assume it has infinite input impedance and requires zero external bias current). This means that all the current in the diode must flow through the resistor, so $I_D = I_R$.

In $I_D = I_R$ substitude I_D with the diode equation from above and I_R with $-V_O/R$. Then rearrange to make V_O the subject:

$$V_o = -I_S R\left[\exp\left(\frac{V_I}{V_T}\right) - 1\right]$$

This equation is of the same form as the generic exponential voltage amplifier discussed above, with input scaling by $1/V_T$, output scaling by $I_S R$, and an offset with respect to the natural exponential so that (with an ideal op amp) $V_O = 0$ when $V_I = 0$. As with the logarithmic amplifier, we note that with V_T and I_S being dependent on temperature, then so is the amplifier output. More on this shortly.

Transistor-based exponential amplifier

Like logarithmic amplifiers, it is common to use a transistor rather than a diode for the PN junction. The basic circuit is shown in Fig.5. The input is applied to the base-emitter junction of the transistor and the collector current is applied to the transconductance amplifier. The circuit shows the base grounded and the input applied to the emitter, but it could be the other way round, as long as V_{BE} is set by the input. With an NPN transistor (as shown) the input voltage needs to be negative to give a positive V_{BE} for transistor to conduct. The circuit is inverting, like the one in Fig.4, so the output is positive with the negative input. The circuit can also be built with a PNP transistor and positive input voltage.

For musical applications it is useful to know the voltage change at the input for a doubling of the output (an octave change). For two inputs to the circuit in Fig.5, V_{BE1} and V_{BE2} which result in a factor of two change in the output we can take the ratio of the diode currents:

$$\frac{I_{D1}}{I_{D2}} = 2 = \frac{I_S \exp(V_{BE1}/V_T)}{I_S \exp(V_{BE2}/V_T)}$$

Simplifying by cancelling the I_S terms and rearranging the exponents gives:

$$\exp\left(\frac{V_{BE1}}{V_T} - \frac{V_{BE1}}{V_T}\right) = 2$$

Taking natural logs of both sides and rearranging results in:

$$V_{BE1} - V_{BE2} = V_T ln(2)$$

At 27°C V_T is about 26mV so $V_T$ln(2) is about 18mV. We need an 18mV per octave control voltage at the base-emitter junction of a transistor to obtain a suitable exponential control current or voltage. This can be easily scaled by an input circuit to give a more convenient (and typically used) 1V per octave overall.

An input step of 18mV to double the output voltage can be illustrated by the LTspice simulation schematic shown in Fig.6. The resistor is chosen to give convenient output voltages for the point of illustration, for example 100, 200, 400 and 800mV. The simulation steps the input in 18mV increments so that the relevant data points are clear to see. The result, shown in Fig.7, shows the doubling of output voltage with the 18mV input steps. The graph has straight lines because of the minimal number of data points. Running this with a much smaller step size would produce a smooth curve.

Temperature effects and thermal compensation

As mentioned above, and as discussed for the logarithmic amplifier, the basic implementations of these circuits are

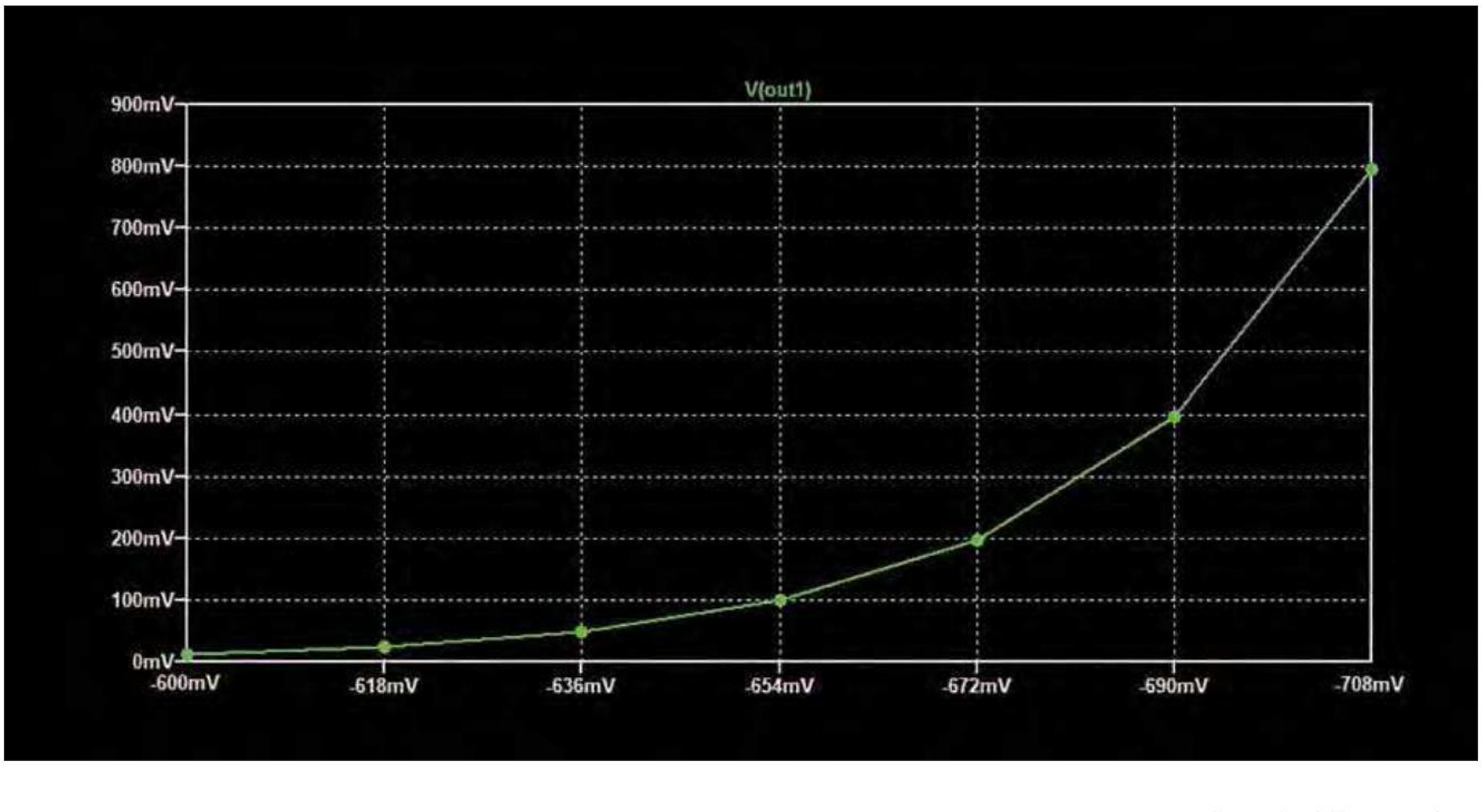


Fig.7. Results from LTspice simulation of the circuit in Fig.5

very sensitive to temperature. Above, we found that the voltage change required to double, or half, the output was $V_T\ln(2)$ (= 18mV at 27°C). This depends on V_T but not on I_S. V_T varies linearly with temperature so it is relatively easy to compensate for – a resistor with the right temperature coefficient used in the gain-setting of an input scaling amplifier will do the job.

A problem remains in that the absolute transistor current, which is doubled or halved by the 18mV voltage change, depends on both I_S and V_T and hence on temperature. One way to address this is to set up the transistor that is used for the exponential function (Q1 in Fig.5 and Fig.6) with a reference V_{BE} which is compensated for temperature changes, and arrange the input voltage to shift the transistor V_{BE} relative to the operating point.

The circuit in Fig.8 is based on this idea. Transistor Q1 is used to provide the exponential function. Its base-emitter voltage is equal to the base-emitter voltage of Q2 minus the input voltage. If the input is 0V then the two transistors will have the same V_{BE} – this will set the reference current. Changes in V_{In} will shift the V_{BE} of Q1 away from this point. An input of 18mV will reduce the V_{BE} of Q1 by 18mV, halving the output. An input of –18mV will increase the V_{BE} by 18mV, doubling the output.

The current in Q2 is kept constant by the feedback loop provided by op amp U2. The feedback ensures that the voltage difference between the op amp's inputs is zero. This means that the collector of Q2 and one end of R2 are at 0V. Thus, the current in R2 is constant at V_P / R2 (V_P is the positive supply voltage). Assuming no current flows into the op amp, all the current in R2 flows in Q2, so Q2 has a constant current and its V_{BE} will be whatever is required to achieve this. If the temperature, and hence the transistor behaviour changes, then the V_{BE} of Q2 will alter to keep the current constant. With zero input, Q1 will have the same V_{BE} as Q2 and so will also keep the same current as temperature varies. Thus, the input voltage will be shifting the current in Q1 relative to a reference point that does not change with temperature. R3 limits the op amp output current to prevent damage to the transistors and C1 reduces gain at high frequencies to improve stability. A similar circuit can also be used to provide temperature compensation for a logarithmic amplifier.

This circuit requires the transistors to be matched and at the same temperature. The latter can be acheived by clamping them together or placing them very close together on a heatsink.

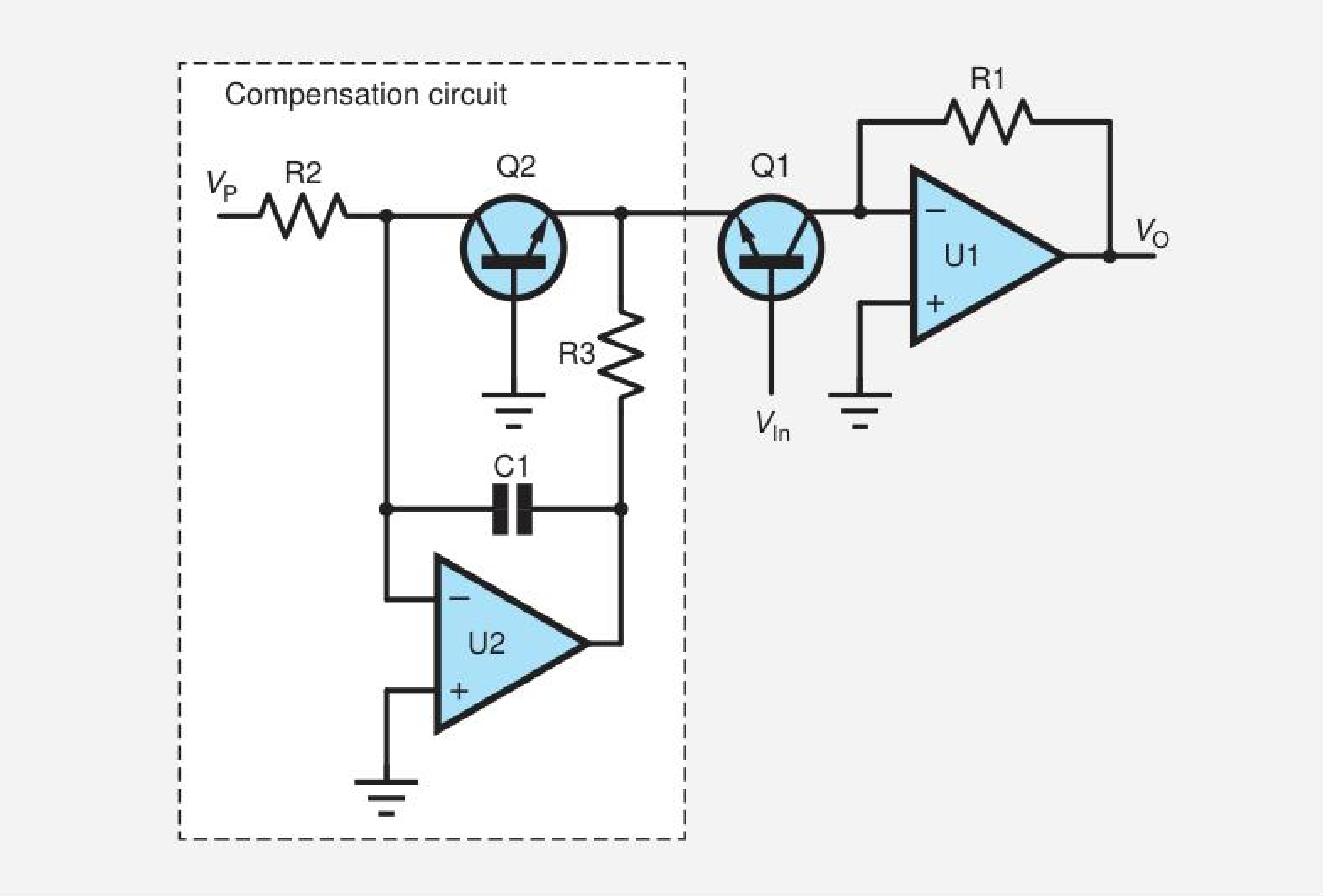


Fig.8. Exponential amplifier with temperature compensation

Correction to Circuit Surgery, December 2021

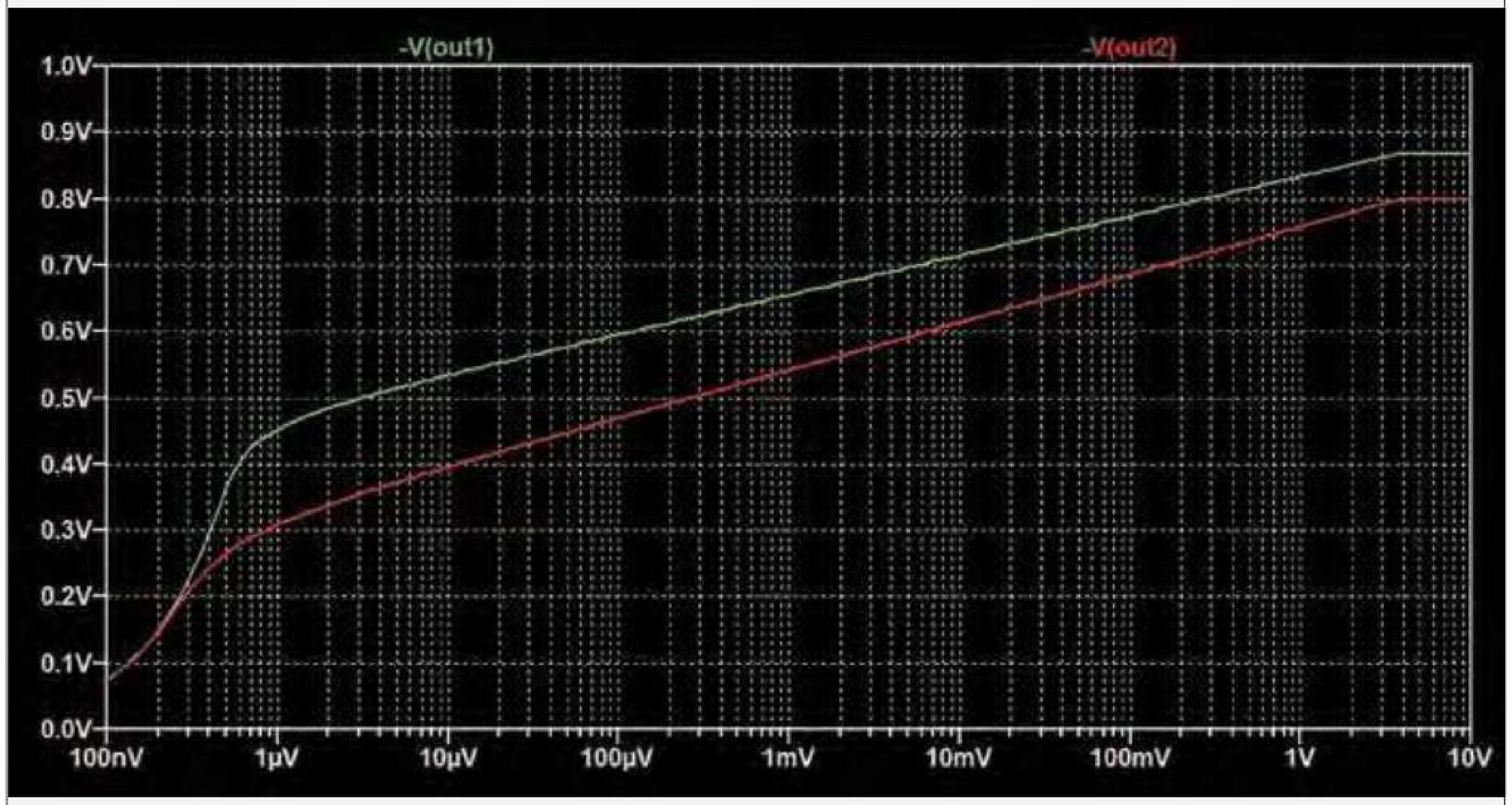


Fig.10. Results of the temperature-effect simulation.

The sharp-eyed among you no doubt spotted a gremlin that worked its way into last month's (December 2021) *Circuit Surgery*, at the end of the article.

Unfortunately, Fig.10 was a repeat of Fig.8. The correct graph is shown above. Apologies for the confusion and any resultant head scratching!

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

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AUDIO OUT

By Jake Rothman

Analogue Vocoder – Part 3: Driver Amplifier

Last month, I mentioned that driving all the filters in the *Vocoder* needed a small power amplifier because a single op amp has insufficient output current capability. This month, we'll discuss the design and next month the build of a special current-boosted op amp circuit. For a small-scale manufacturer like me, it's rarely cost-effective to design a circuit and PCB for just one job, so this is a versatile audio module that can double as a high-quality headphone amp, mixer, spring-line driver, output transformer driver and even a high-impedance speaker driver. It can have a balanced input and two boards can be used in bridge mode.

It's used as a virtual earth mixing amplifier – it mixes all the *Vocoder* filter outputs together, along with the synthesiser and vocal inputs. Also, its high-current output can drive transformers to give isolated balanced XLR outputs. These options are shown in Fig.1.

Circuit description

An effective way to boost an op amp's output current is to put a couple of complementary transistors in a push-pull emitter-follower configuration on the output. These are included within the overall negative feedback loop, as shown in Fig.2. This configuration is very tolerant of H_{fe} mismatching between the transistors. To retain the low distortion of the NE5534 op amp, a few additional tweaks and refinements are needed. The full circuit is shown in Fig.3.

Output stage

The output stage consisting of TR1 and TR2 is class AB. This allows high current peaks of around 500mA. A small idling or quiescent current (I_q) with zero signal of around 5 to 15mA through the transistors is necessary to avoid crossover distortion. In most power amplifiers the bias voltage to set I_q is achieved by a pre-set resistor in conjunction with a V_{be} multiplier transistor. In this circuit's case, since the output is expected to drive loads upwards of 50Ω, we can use a fixed bias voltage to set I_q. This is possible because loads of 4Ω or 8Ω do not have to be driven as in normal power amplifiers and larger emitter resistors can be used without significant power loss. If R11 and R12 are around 10Ω to 33Ω, rather than the typical 0.22Ω, sufficient DC negative feedback voltage (V_{re}) is dropped across them to stabilise the bias current. These high-value resistors will also provide a degree of short-circuit protection – but not for long.

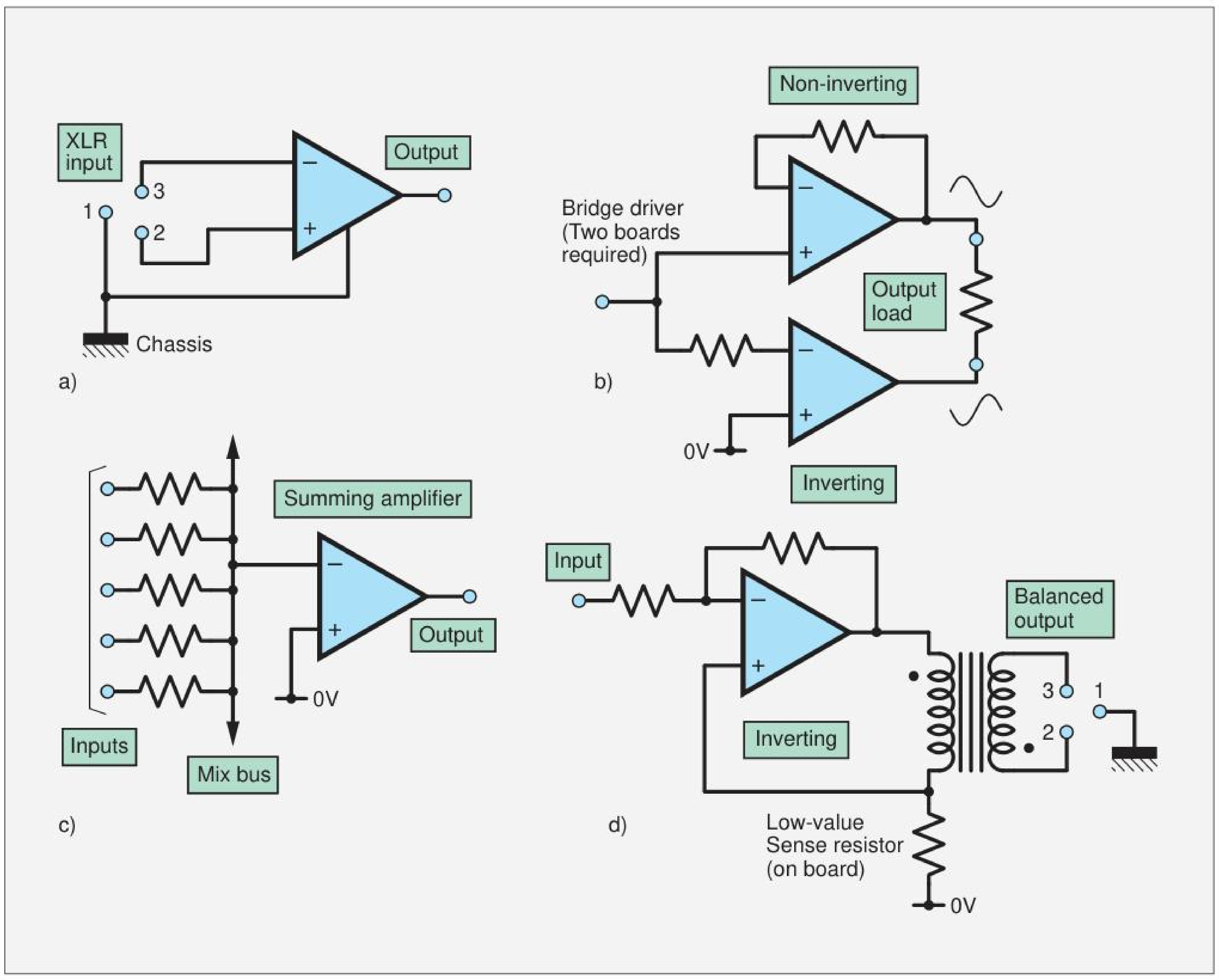


Fig.1. Variations using the same board: a) differential/balanced input amplifier; b) summing/mixing amplifier; c) bridged driver and d) distortion-cancelling transformer driver.

Biasing

The extra emitter resistor voltage drop (2× V_{re}) is added to the base emitter voltages (V_{be}) of the transistors – therefore, the bias voltage needs to be higher than the normal 1.2V (two diode drops) used. A fixed bias voltage of 1.5V is required. I've done a bit of research on ways of achieving this; one is to use a BZV46 'Stabistor' diode which is now hard to source, and another is an infra-red LED. In this circuit, I've chosen to use two Zener diodes (D1 and D2) which because of their high doping, exhibit a higher *forward* voltage of typically 0.75V, rather than 0.6V. (Note, Zener diodes are normally run in *reverse* breakdown and this is the device voltage specified). Whatever the Zener *reverse* voltage is, say 5.6V, 12V or 3.3V,

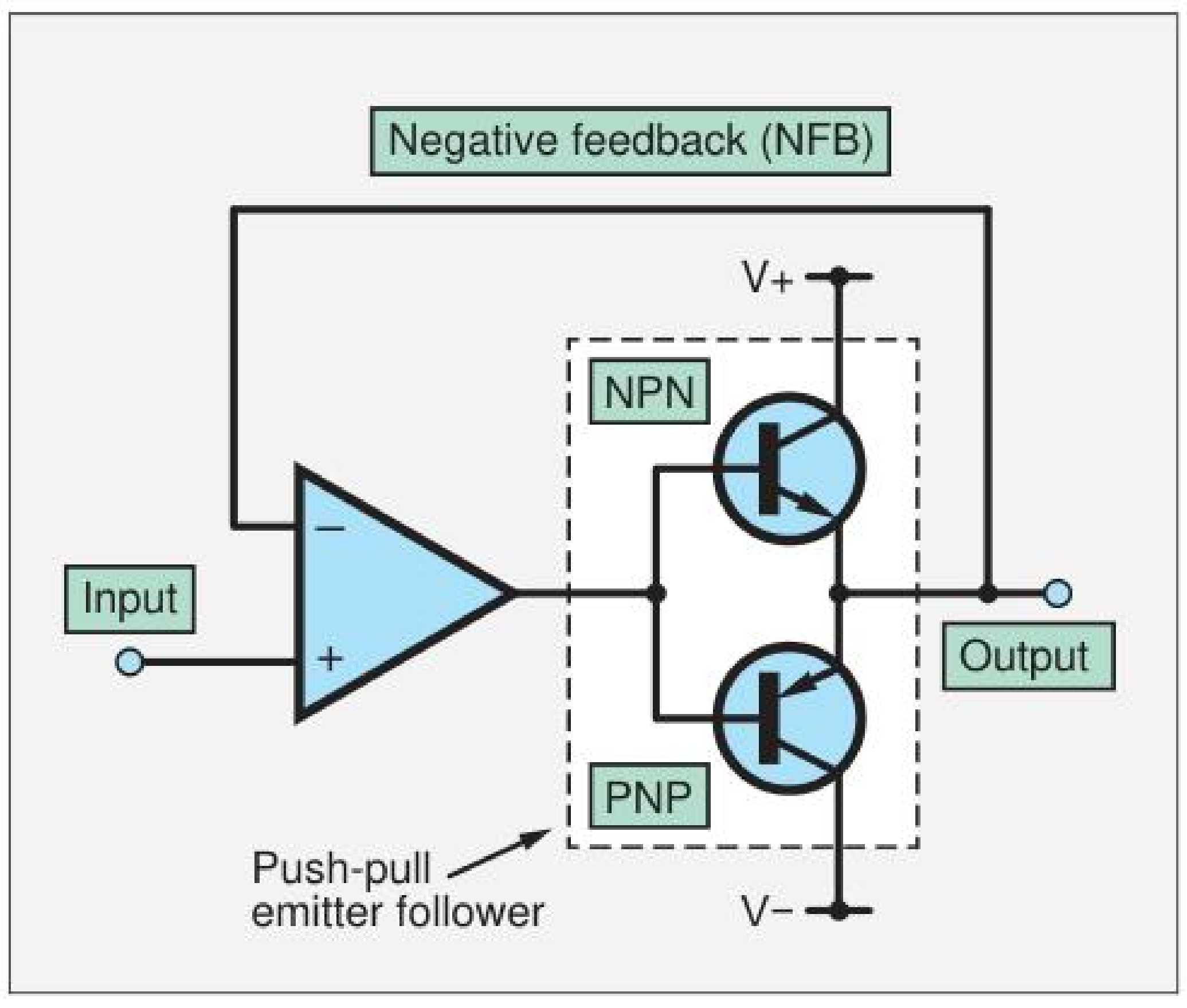


Fig.2. The output current of an op amp can be boosted by adding an emitter-follower to the output.

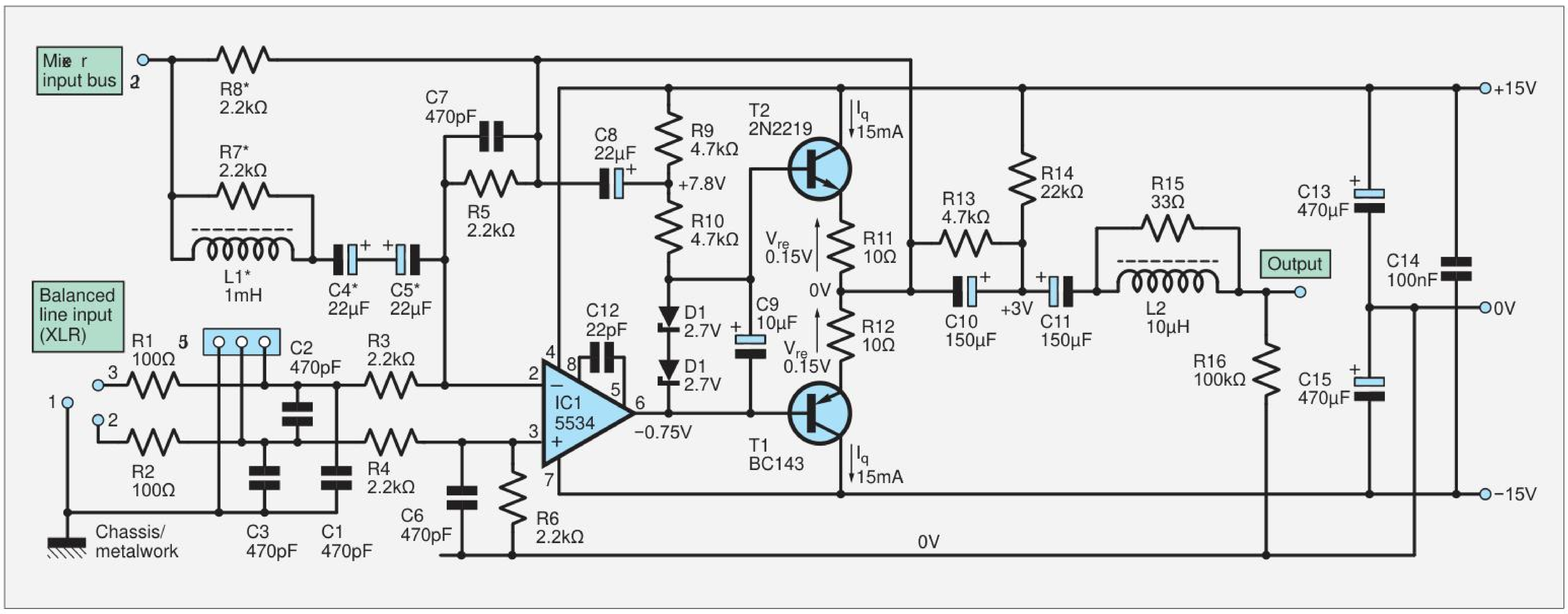

Mixer input bus
2
R8*
2.2kΩ
R7*
2.2kΩ
L1*
1mH
C4*
22µF
C5*
22µF
C7
470pF
R5
2.2kΩ
C8
22µF
R9
4.7kΩ
+7.8V
R10
4.7kΩ
T2
2N2219
Iq
15mA
Vre
0.15V
R11
10Ω
0V
R12
10Ω
Vre
0.15V
T1
BC143
Iq
15mA
C9
10µF
D1
2.7V
D1
2.7V
C12
22pF
IC1
5534
−0.75V
Balanced line input (XLR)
R1
100Ω
R2
100Ω
C2
470pF
R3
2.2kΩ
R4
2.2kΩ
C3
470pF
C1
470pF
C6
470pF
R6
2.2kΩ
Chassis/ metalwork
R13
4.7kΩ
R14
22kΩ
C10
150µF
+3V
C11
150µF
R15
33Ω
L2
10µH
R16
100kΩ
Output
C13
470µF
C14
100nF
C15
470µF
+15V
0V
−15V
0V

Fig.3. Full circuit of the high-output-current amplifier. Note that the main circuit is for a differential input amp. Note, R8 is not normally used. (Components marked '*' are for the mixer amp.)

its *forward* voltage will be around 0.75V. One advantage of using two diodes, is that each can be mounted adjacent to its associated output transistor's heatsink to provide a degree of temperature compensation (see Fig.4). Alternatively, transistors can be used as diodes. The base-emitter junctions of small-signal types, such as the BC549, give around 0.7V. It's easier to couple transistors to heatsinks than using diodes, as shown in Fig.5. The fastest tracking thermal compensation can be achieved by mounting the bias transistor on top of the can – see Fig.6. A small bit of stripboard provides rigidity and allows a 500Ω preset to be fitted in series with the 'diodes' to increase and trim I_q if wanted.

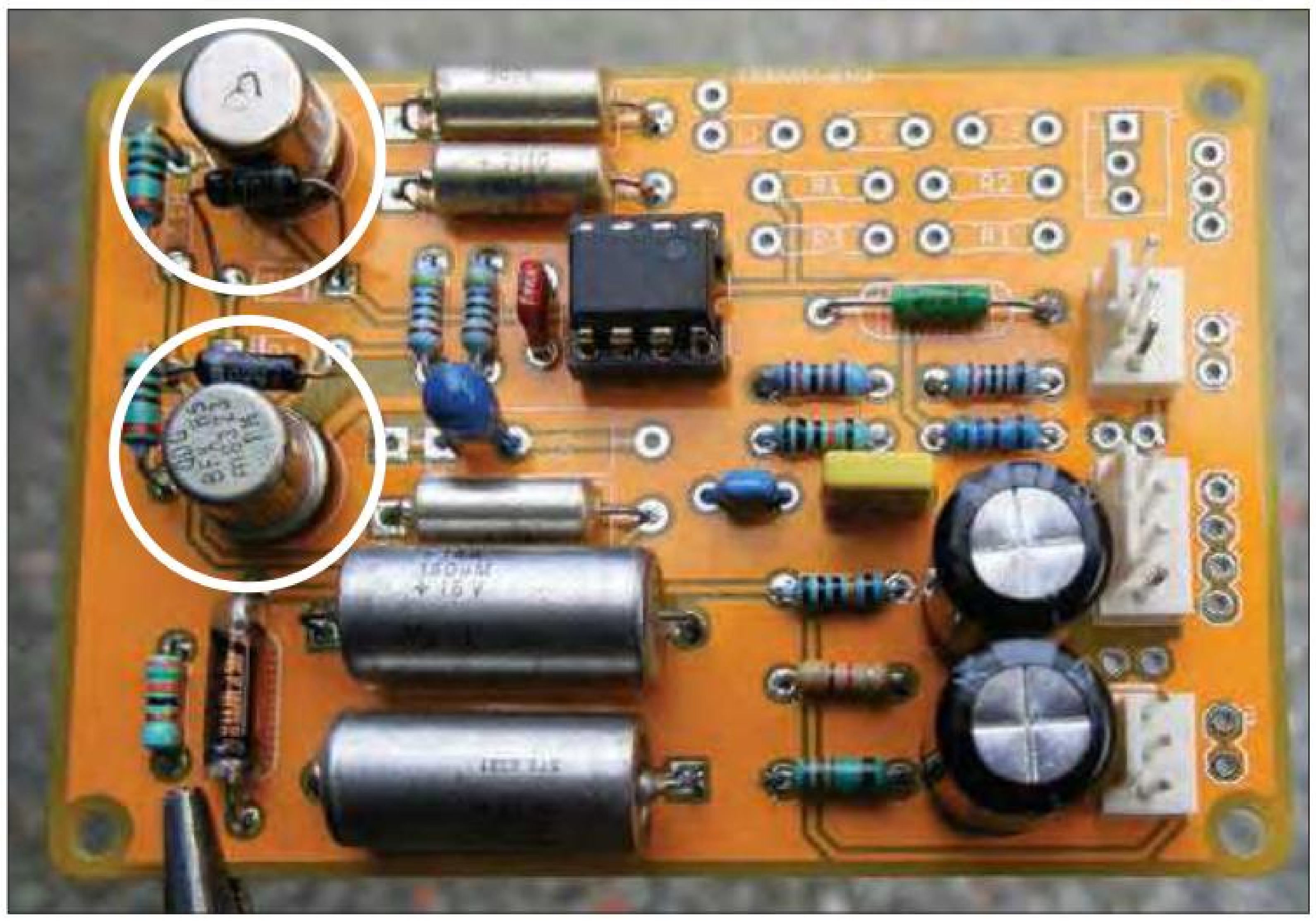


Fig.4. Each Zener bias diode (D1 and D2) should rest against their associated heatsink/transistor to provide thermal compensation.

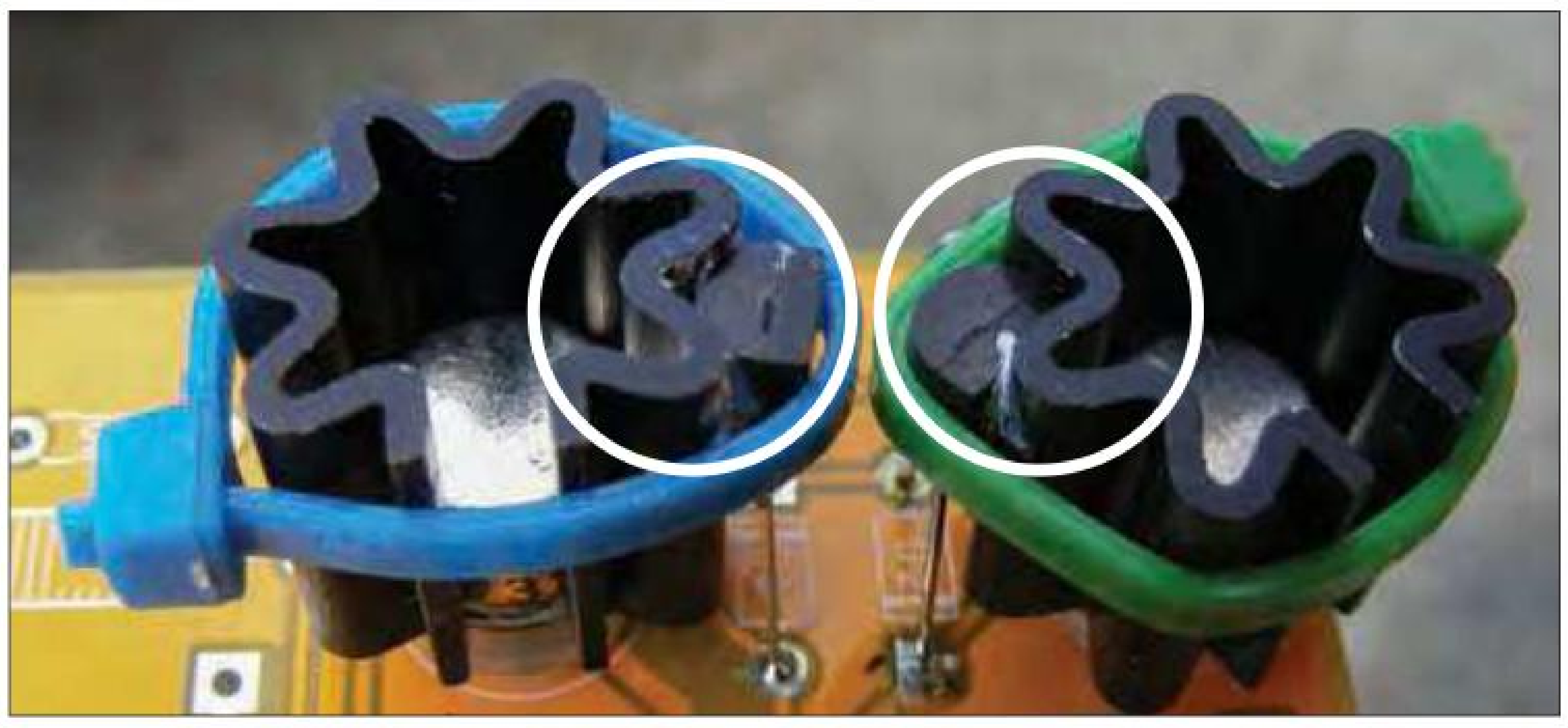


Fig.5. An alternative to Zener diodes is to use the base-emitter junction of small-signal transistors as diodes – here clamped to the driver transistors' heatsink.

The diodes themselves need a bias current to generate the bias voltage. This is provided by R9 and R10 connected to the 15V power rail. This can be thought of as a single resistor of 9.4kΩ with 13.5V across it. (15V power rail minus the 1.5V diode bias voltage). Using Ohm's law ($I = V/R$) we can calculate the current as 1.4mA. The exact value is not critical, but this is the minimum. The current is sunk into the op amp's output pin. This sounds like a bad idea, but audio designers have found that a DC bias current can reduce op amp distortion. It was a popular trick to reduce the distortion of cheap op amps, such as the LM324, 741 and LF351. It was usually done by connecting a 3.3kΩ to 10kΩ resistor from the output pin to the negative rail. Douglas Self later discovered that the popular audio op amp – the NE5534 used here – gave lower distortion with the resistor going to the positive rail. Thus, the diodes' bias current should be beneficial. Noise from the power rail is suppressed by the op amp's low output impedance.

Clipping

There is a little loss of headroom with the diodes connected in this way because the op amp's output pin sits at −0.75V with the output at 0V. This means the lower cycle clips first. This is not a problem in practice, since it is only a reduction from 24V peak-to-peak to 22V into 50Ω with ±15V rails, a loss in headroom of −0.75dB, which is inaudible. It can't be fixed by the normal offset adjustment pins on the chip because

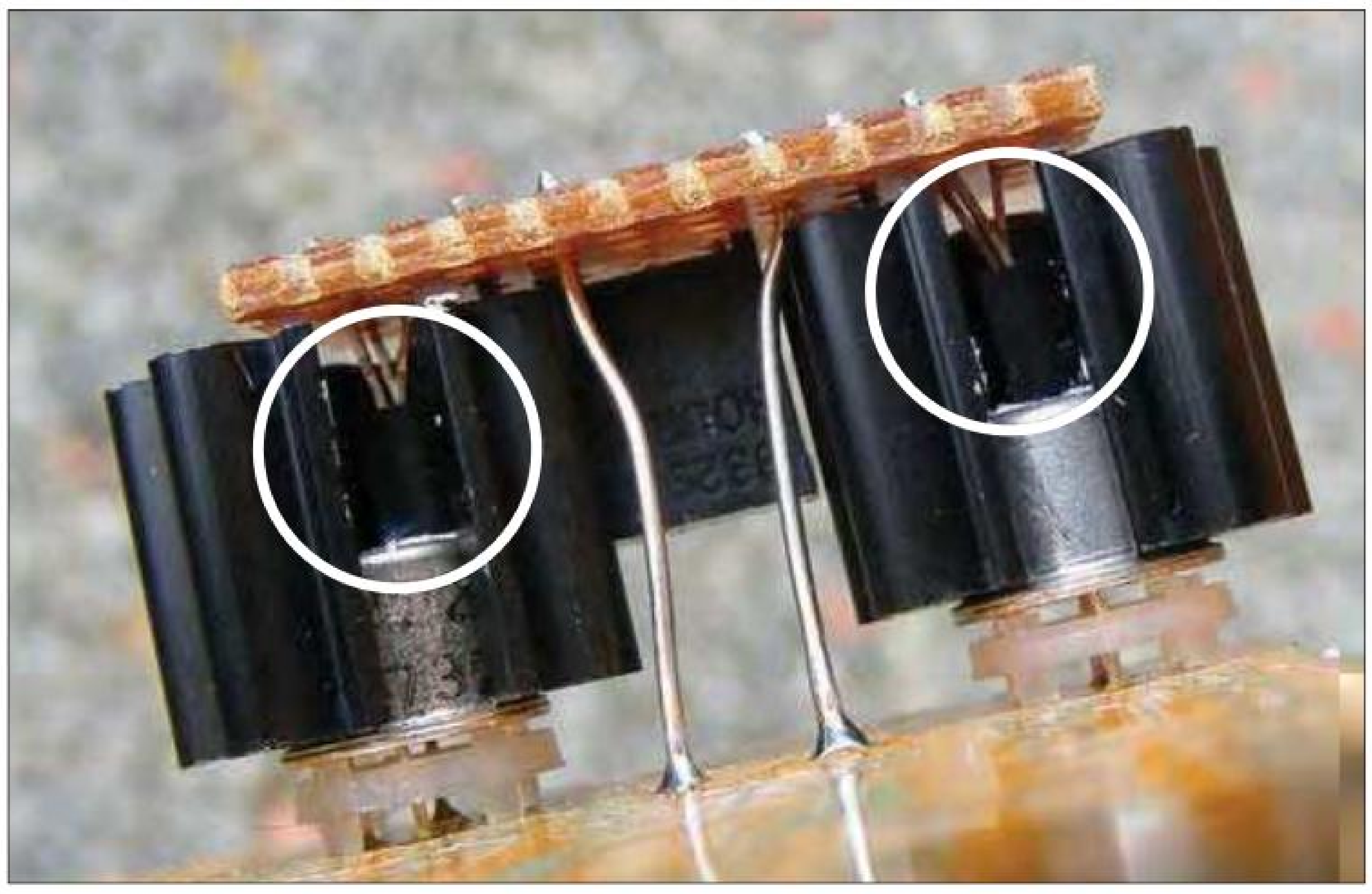


Fig.6. A superior but rather complex way of ensuring good thermal coupling between transistors is to use a small board wired as shown. A bit of heatsink compound helps the coupling from the top of the transistor cans to the biasing devices.

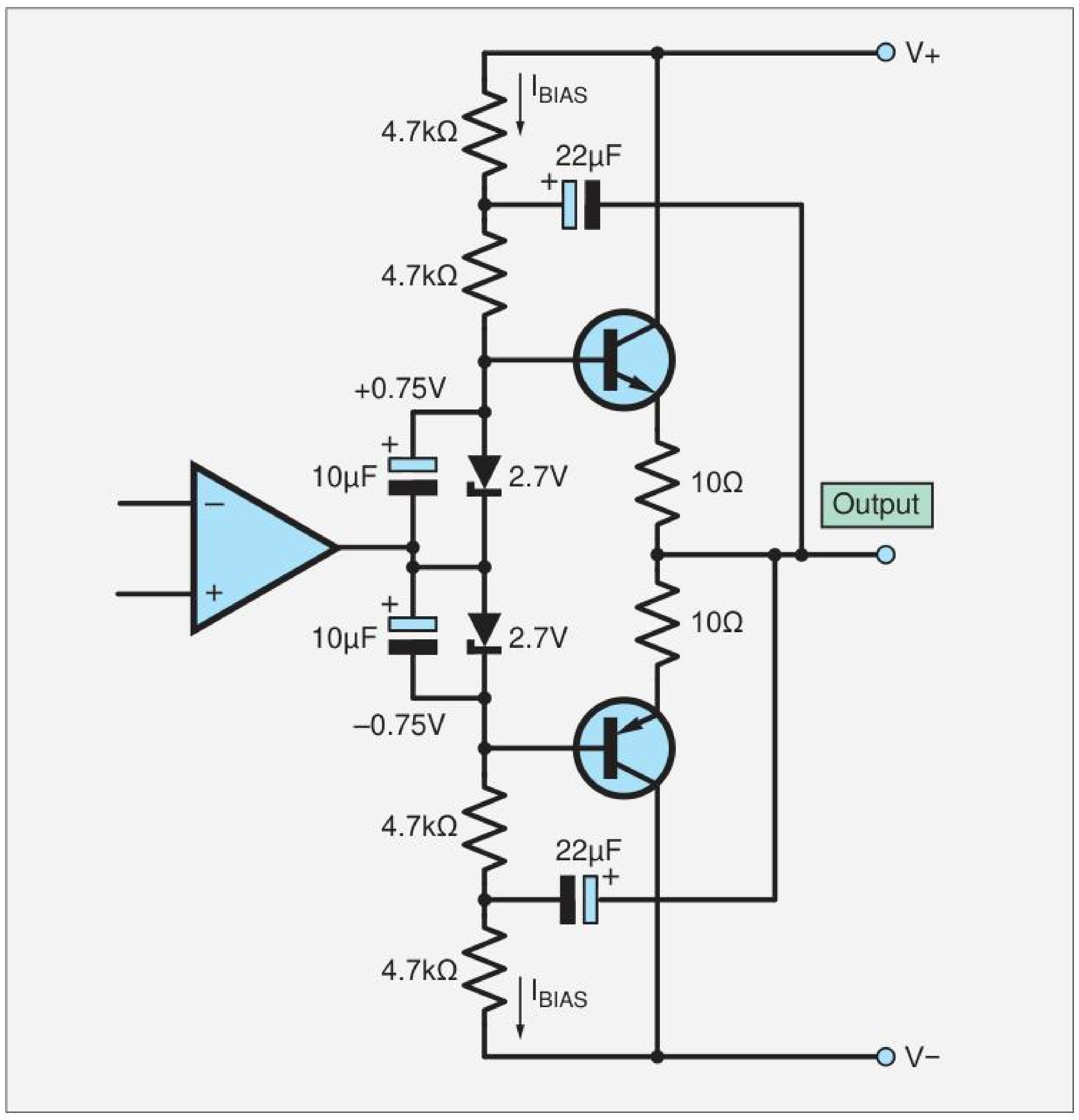


Fig.7. A symmetrical bias chain with a dual bootstrap minimises offset and current into the op amp's output.

the range is not sufficient. If it's good enough for Focusrite (a high-end audio manufacturer), who use a similar output circuit with 5532s, it's good enough for me.

For those who are driven by 'scopemanship', the problem can be eliminated by making a symmetrical biasing-plus-bootstrapping network, as shown in Fig.7. This needs two extra electrolytic capacitors and two resistors.

An alternative, for the differential amplifier is to inject an offset current into one of the op amp inputs. In Fig.3, add a 180kΩ resistor from the –15V rail to the op amp's inverting input, plus change R5 to 10kΩ to provide a little extra gain. Power rail noise injection could be a problem, raising distortion. However, this method does avoid any DC voltages appearing on the inputs. Alternatively, the non-inverting input can be jacked up by one diode drop with filtering (Fig.8). This works well for the summer amplifier. Another trick once used by Quad in their pre-amps, is to make the power rails slightly asymmetrical. For this design +14.4V and –15.7V works. It's confusing though, if someone has to fault-find later.

High-voltage upgrade.

The 5532 is unusual among op amps in that it can withstand ±22V power rails. This is the absolute maximum stated on the datasheet, but in practice I've found the Signetics/Texas NE5534P remains reliable at this level. (Note: the dual version, the NE5532 gets too hot). This will give 35.5V pk-pk output into 80Ω (1.97W RMS). With the diode mod (Fig.8), 36V pk-pk (2W RMS) will be obtained. By replacing the 5534 with a Texas Instruments OPA604, the power rails can be increased to ±24V, giving 38V pk-pk output into 80Ω. Interestingly, the OPA604 does not exhibit the asymmetrical clip, so it needs no diode bias. However, this is only because it clips earlier on the positive cycle than the 5534. On ±22V the output is 35V pk-pk, half a volt less than the 5534. So, the OPA604 upgrade is only worth it if you use ±24V rails or if you need a FET input device for high impedances. It also costs three times more. (currently, the 10-off price is £0.77 vs £2.27 + VAT at Mouser). Compensation isn't needed with the OPA604 since it is unity-gain stable. It's fine to leave the 5534 compensation capacitor (C12) on the board for this upgrade, since there is no connection to its pin 8.

Bootstrap

Another useful little tweak is to bootstrap the mid-point of resistors R9 and R10 with capacitor C8. This prevents the resistors loading the op amp's output and boosts the maximum positive output swing a little. C9 bypasses the diodes to provide better AC drive to the base of TR2. R13 and R14 bias the output coupling electrolytics C10 and C11 at around 3V. This also reduces distortion, especially with tantalum types. Again, the current from these biasing resistors is sunk into the op amp's output. These capacitors are dimensioned to feed 600Ω. For lower impedances, a noticeable increase in low frequency distortion will occur. R16 is a pull-down resistor to hold the output at 0V to avoid pops when leads are plugged in. Without this resistor, the output will float up to the capacitor's bias voltage. Input coupling capacitors C4 and C5 form a bi-polar unit which also reduces distortion. I found there was no further benefit in biasing these.

High-frequency stability

C1, C2 and C3 are RF filtering for balanced inputs. C6 provides RF filtering on the non-inverting input and C7 is the normal feedback phase-lead capacitor needed for stability. R15 and L2 allow loads with significant capacitance, such as long cables, to be driven without oscillation. This problem often affects emitter followers. Normally, R15 is sufficient to prevent this, but if a very low output impedance is necessary, it can be bypassed at audio frequencies by adding L2.

Since this is a high-current op amp circuit, decoupling capacitors C13 and C15 have to be much bigger than usual to cope with the high peak-current demands. This means that they can inject high ripple currents into the ground rail, possibly causing distortion and hum. The PCB layout is designed to deal with this by placing the capacitors where the power supply comes into the board. There are two pins and wires for the earth on the power connector to give minimum impedance. Another decoupling capacitor (C14) is necessary for high-frequency stability, and this must be placed close to the op amp. The 5534 in particular, will oscillate without this capacitor.

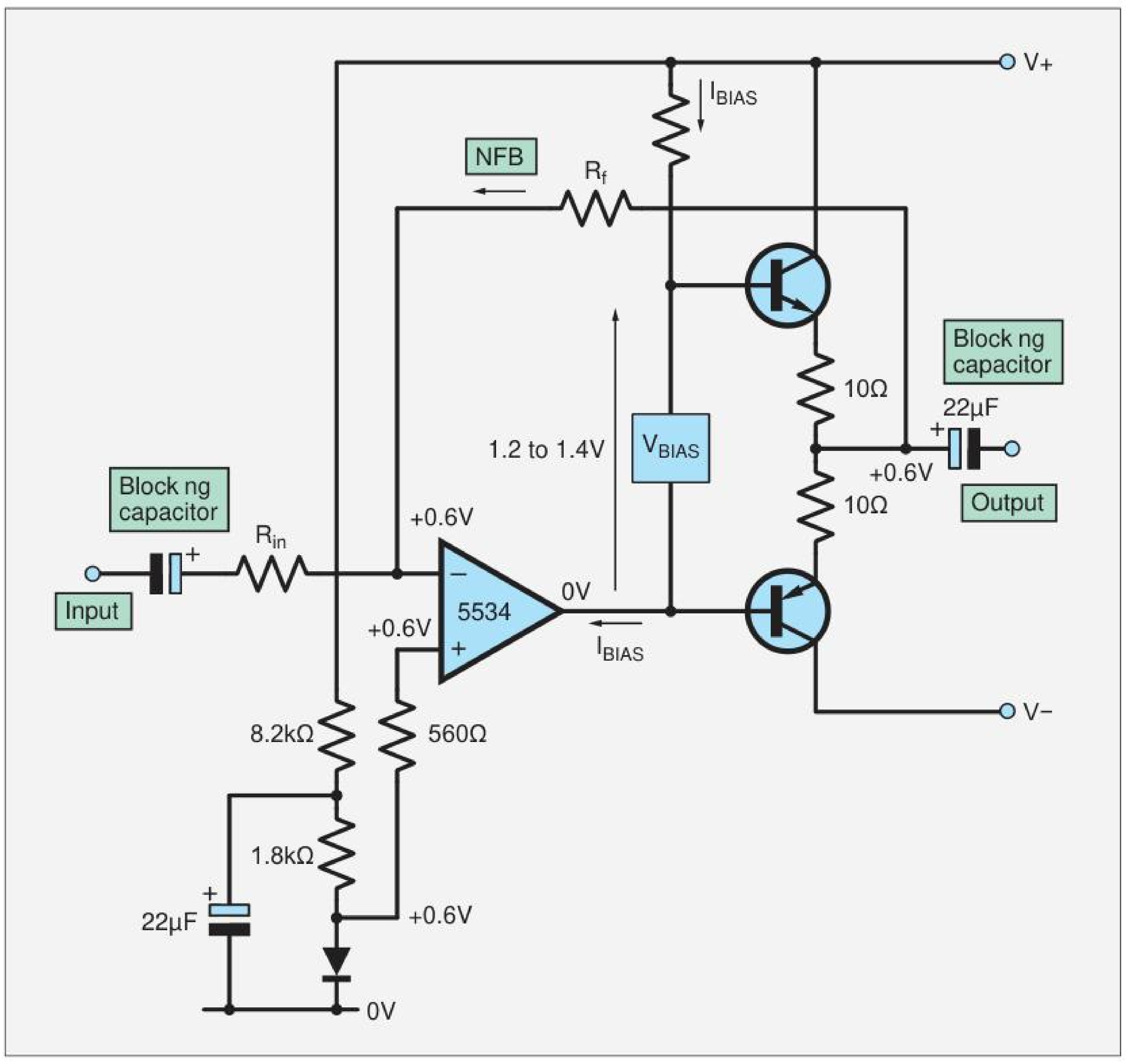


Fig.8. A diode voltage applied to the non-inverting input cancels the offset created by the output bias network.

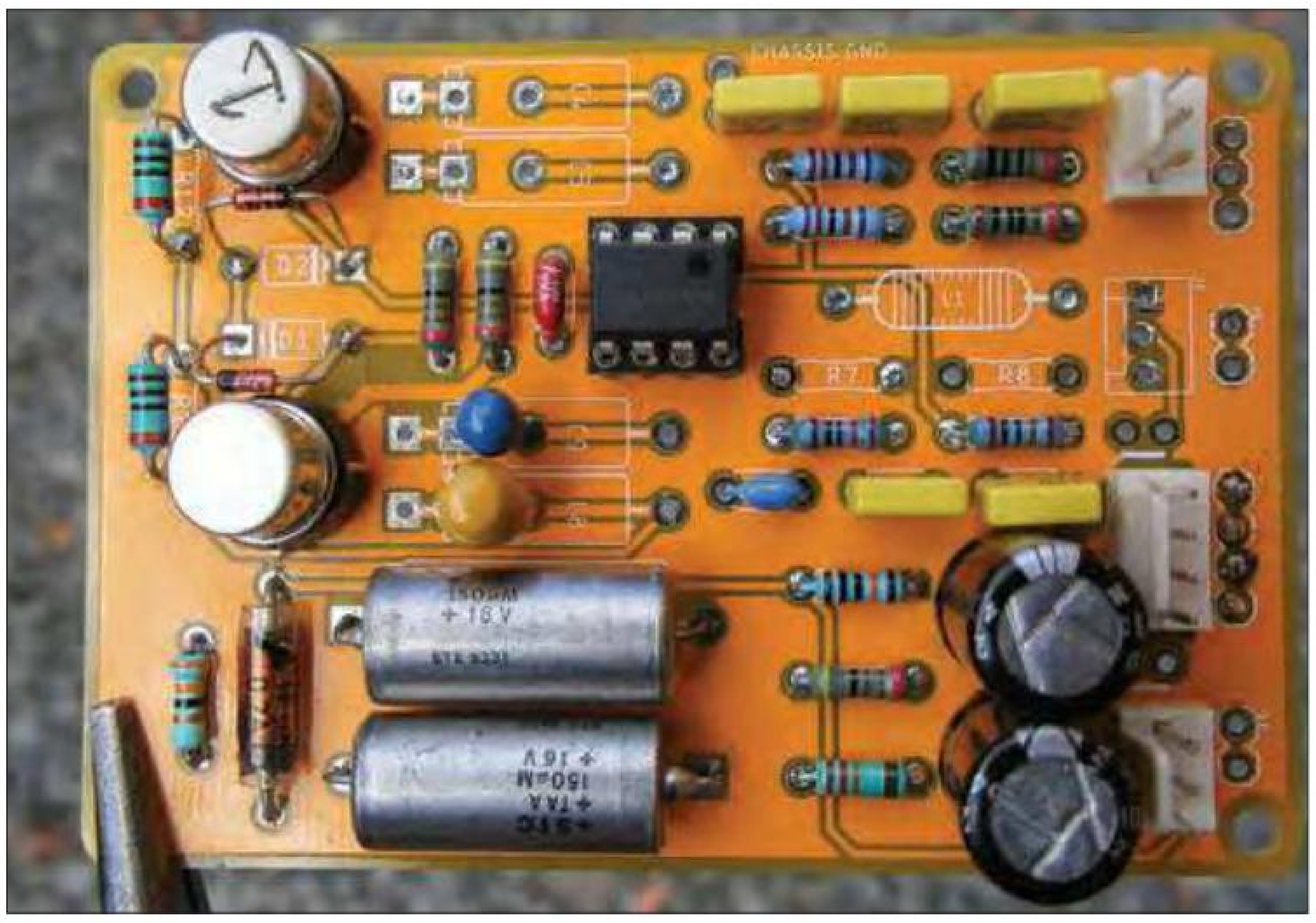


Fig.9. The completed differential input board.

R8 is another bootstrap component for use on summing and inverting amplifiers. This is a circuit trick developed by Calrec to multiply the input capacitors (C4 and C5) value by 10 times, avoiding bass loss when the total input impedance is low. This situation occurs when lots of inputs are summed together, as is the case for the *Vocoder* and mixing desks. If, for example, 10 4.7kΩ input resistors are used to sum 10 inputs, the effective impedance will drop by a factor of 10 to 470Ω. The expected –3dB point would be 33Hz, but with the 'Calrec mod' this is reduced to 3.5Hz. Note that the op amp feedback resistor is 100kΩ to maintain a DC path, while allowing sufficient AC feedback around the capacitors. Interestingly, the bootstrapping also appeared to eliminate distortion from the capacitors.

Compensation

C12 is a compensation capacitor for the op amp. If its value is too low, the amplifier will oscillate, if too high, the distortion around 10kHz will increase. If the gain of the amplifier is set to unity, the capacitor specified in the data sheet is 22pF, but it can often be reduced to 15pF in practice. For gains over five it can be omitted. For a gain of six, 6.8pF gives lowest distortion. If used for mixing multiple inputs with unity gain, the effective gain is increased in proportion to the number of inputs, so C12 can also be reduced for this reason. This is assuming the output transistors used are fast planar types with an F_t of over 50MHz. If slow (F_t of 1-4MHz) then types such as BD436/7 are used, and greater compensation may be needed, with a consequent increase in high-frequency distortion.

Uses and configurations

I explained in the introduction that this board can be configured in several ways – here are the *Vocoder*-specific examples.

Balanced input Vocoder driver

The amplifier is a standard differential configuration to allow for a standard XLR balanced input. The input resistors can be adjusted to give a different range of input impedances. Often, 10kΩ is the standard value, but this can give a significant noise contribution. I often use much lower values, such as 1.5kΩ, on the basis that most op amps can still drive it. The assembled board is shown in Fig.9.

Summing and Vocoder output amplifier

Here the amplifier has to be configured as a virtual earth summing amp. The input resistors are on the *Vocoder* channels and the input on the board is a virtual earth. I have added a 'Steve Dove inductor'(L1) to decouple RF from the long mixing buses sometimes encountered in mixers. His early 1980s *Studio Sound* series on mixer design is well worth downloading. I'm sure it formed the basis for much of Douglas Self's later publications (see: **https://bit.ly/pe-jan22-ao**). The assembled summing board is shown in Fig.10.

Next month

In the next article we will look at some more board configurations, the components and assembly.

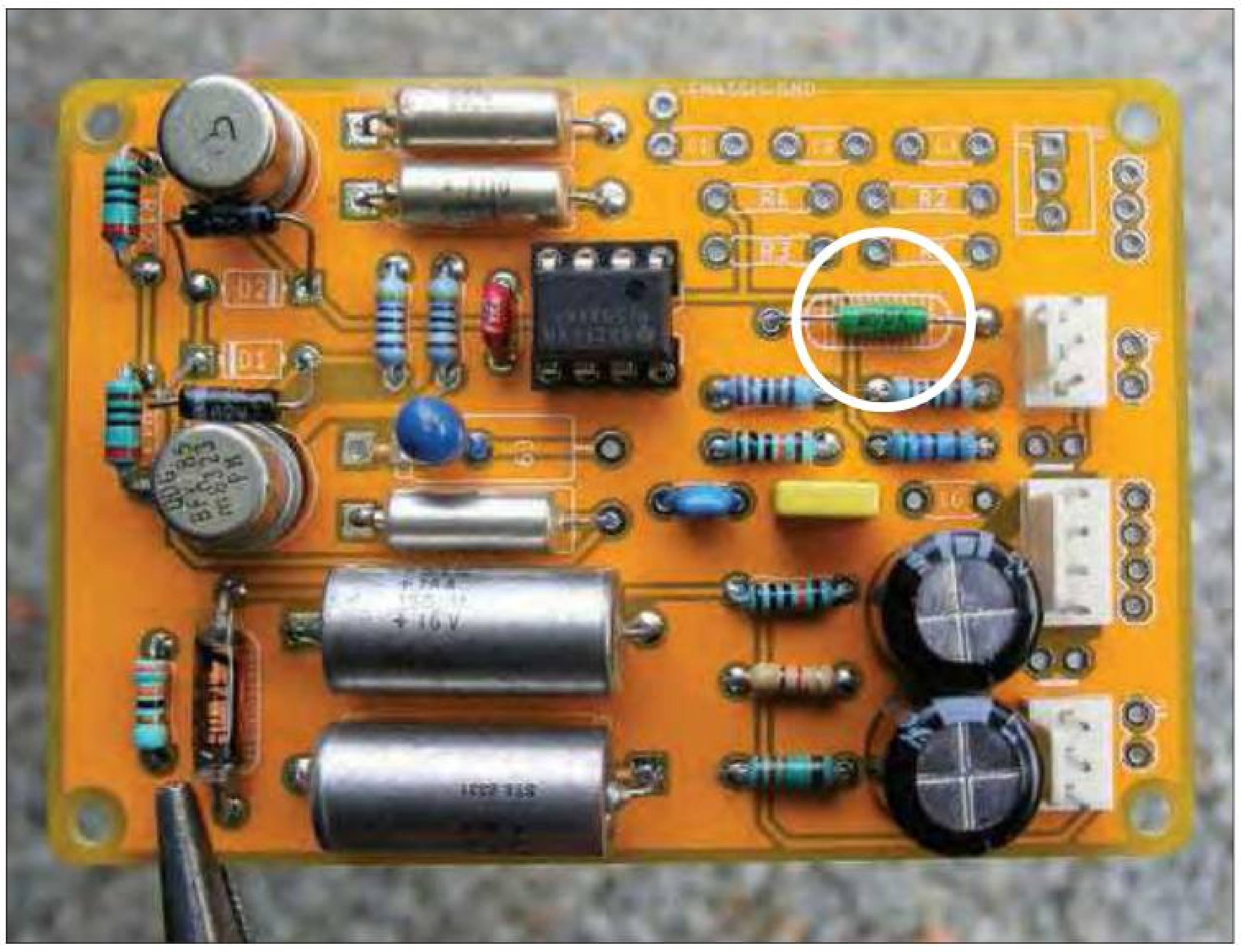
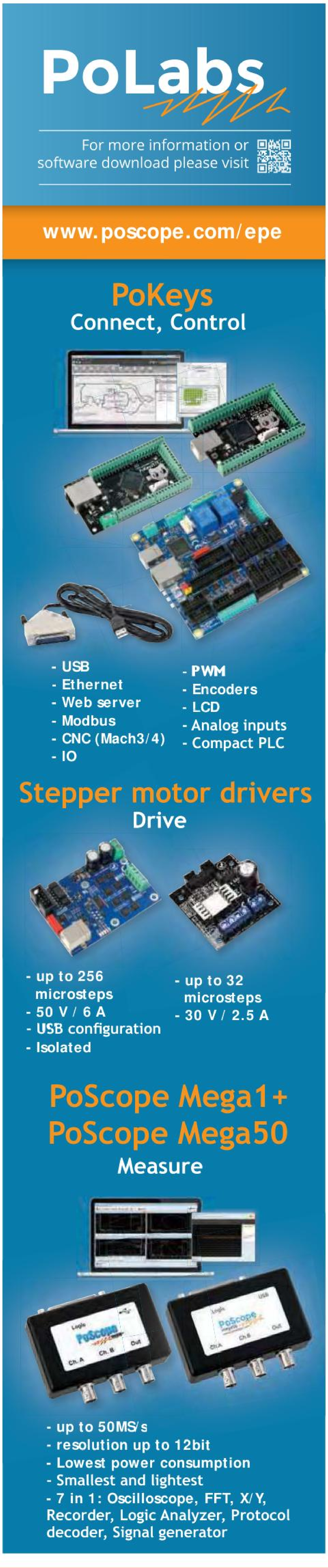


Fig.10. The completed summing amplifier board. Notice the green inductor (L2) which is needed for use with long mix buses.



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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 32: Using iButtons with the Micromite

This month, we are going to look at interfacing the Micromite with a handy little gadget called the 'iButton'. If you don't know what an iButton is, then simply consider it as an electronic device that contains a digital identification number (ID), housed in in a robust metal case – see Fig.1. Each iButton is programmed by the manufacturer with a guaranteed unique ID, so iButtons are ideal for use as 'electronic keys' to grant the user access to something, somewhere, or simply as a unique identifier when attached to an asset (object or person).

iButton overview

The iButton's metal casing comprises a stainless steel 'can', about the size of three five-pence coins stacked on top of each other (roughly 6×16mm). It is similar to a medium-sized button that you may find on clothing (hence the name), with the 'i' part of the name simply referring to 'information'. iButtons are designed to be mounted in, or attached to, virtually anything. The most common technique is to mount one in a key-fob holder, which in turn can be attached to a bunch of keys – see Fig.2. Note that iButtons can be used in quite harsh outdoor environments, as well as being used indoors.

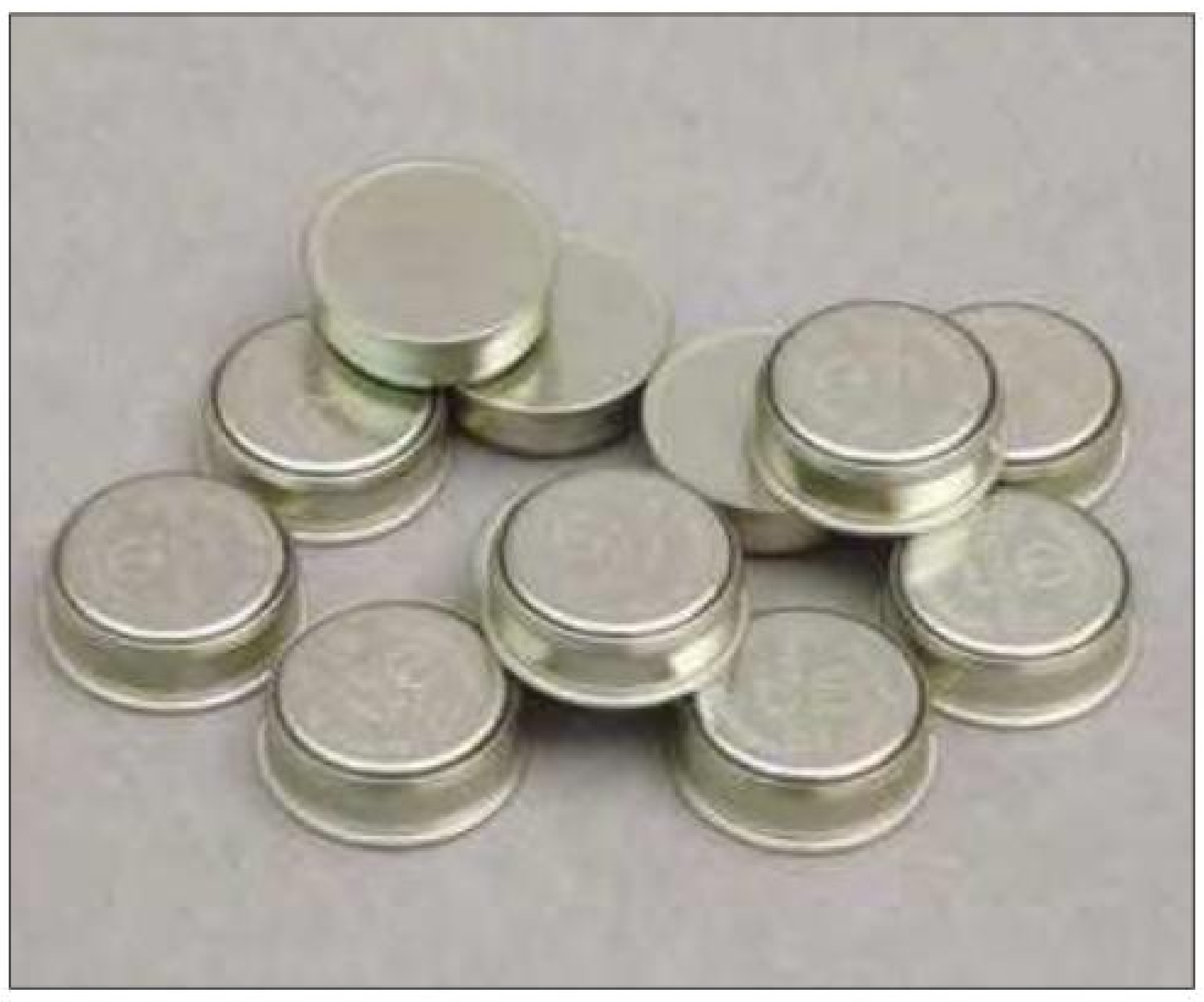

Fig.1. iButtons: each one is approximately 6×16mm in size.

iButton application examples and features

Some examples of their application include using them for electronic door-access (in buildings such as universities, factories, hospitals and retail stores), or being used by staff to access cash tills (often seen in pubs, restaurants and retail outlets). They can even be used as ignition keys for boats, or any other types of outdoor vehicles. A slightly more unusual application is the example of iButtons being attached to farm animals to identify them!

The simplest form of information contained within an iButton is just its own unique ID number. However, different types of iButtons are available, each offering slightly different features, and offering additional information, such as time and date, temperature, humidity, or other 'user-programmed' data.

iButton communication

Information contained in an iButton is accessed and communicated serially over a single data line and is the reason why you will often hear the term '1-Wire' in relation to iButtons. However, this is a little bit misleading because you also need a common ground connection to complete the 'communication circuit' – hence *two* physical wires are required, not just one. The term '1-Wire' simply refers to the protocol used on the single data line, and it is this 1-Wire protocol that the connected device (typically a microcontroller) needs to use to be able to communicate successfully with an iButton.

So how are iButtons connected (electrically) to a microcontroller? Simple, you use an iButton reader. This may sound like it involves some kind of complex device, but the reality is that a reader is nothing more than a pair of

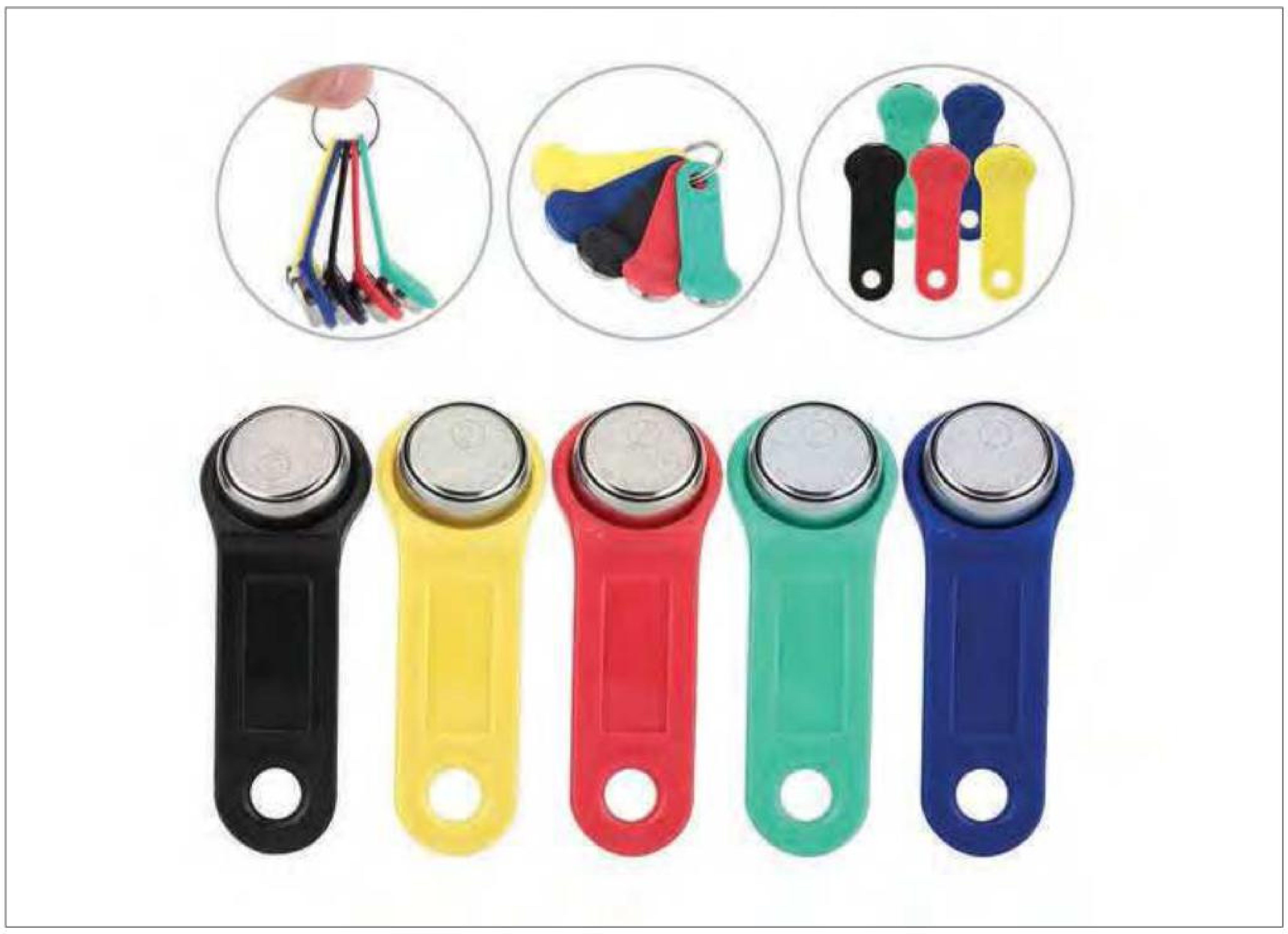

Fig.2. Key fobs are available in a range of colours and make it easy to attach the iButton to a bunch of keys.

metal contacts that connect the iButton's data line (and common ground) through to the microcontroller. In use, all the user needs to do is 'tap' the iButton momentarily onto the reader so that the microcontroller can communicate with the iButton (more on this later). Alternatively, if an iButton is attached to an asset, then instead of referring to a 'reader', the term 'probe' is used.

In this month's article, we will start by explaining some of the basic details regarding iButtons and readers, and will then show you how to use the most common type of iButton (the DS1990) with a Micromite. We will show just how easy it is to use MMBASIC's built-in 1-Wire commands to write a program that is able to read the iButton's unique ID number whenever an iButton is detected.

Next month, we will continue by looking at how to check that the serial data that is read by the microcontroller is valid, noting that there is often a lot of 'contact bounce' present when momentarily touching an iButton onto a reader (or when touching a probe onto an iButton). We will also look at some iButton varieties, specifically one that contains EEPROM, which allows data to be written to it. We will end up by using various elements of these iButton articles in a new mini-project – a modern-day version of the classic 'electronic combination door-lock'. Instead of using a combination keypad, our Micromite-based version will use EEPROM iButtons as the keys, and it will incorporate a touchscreen interface to show not only information about the person who is trying to unlock the door, but also facilitate the control of valid keys.

More about iButtons

The description above has (hopefully) provided a good introduction to iButtons; however, there are several more points that are worth discussing before we start to use one with the Micromite. So next we'll expand on these points and provide you with some interesting background information, as well as highlighting some useful terminology.

Part numbers

iButtons were first manufactured by Dallas Semiconductors in the 1990s, and this is the reason that all iButton part numbers begin with the letters 'DS'. Dallas Semiconductors were acquired by Maxim in 2001, and they continued to expand the range of available iButtons, adding several memory-type iButtons to the line-up: for example, incorporating EEPROM or static RAM (SRAM) technology. The SRAM-type iButtons can be used as miniature dataloggers that are easily attached to an asset so that data (such as temperature) can be recorded at regular time intervals. Even under Maxim, the new iButtons continued to have a part number beginning with 'DS', and there are now around 20 different types, each offering slightly different features.

We won't go into the details of the different part numbers, other than to say that we will be focusing this month on the DS1990 (an *ID-only* iButton), and next month we will use the DS1971 (an *ID plus EEPROM* iButton).

Family code

Each different type of iButton has a part number that begins with DS, and is then typically followed by four digits. This part number then makes it easy for us humans to distinguish between the different versions. However, each different DS part number also has a corresponding byte-value known as the 'family code'. (Note that hexadecimal (hex) values are typically used when talking about iButtons; the reason will become clear shortly.) For the DS1990, the family code is 01 (hex) and for the DS1971 it is 14 (hex). So what is the purpose of the family code?

Put simply, the family code is something that can easily be read by the connected microcontroller to determine which type of iButton is currently 'connected'. This means the microcontroller's software can check to see if the correct (or expected) type of iButton is present. For example, you might want to do this if the microcontroller is expecting an EEPROM-type iButton (eg, a DS1971) to which it needs to write data. The software will not be able to successfully write the data if the user has tapped an ID-only (eg, a DS1990) type of iButton onto the reader. So, reading the family code allows the software to behave correctly, and hence it is good practice to implement this into the program code.

Unique ID number

Even though the various iButton types offer slightly different features, the one thing that they all have is a unique ID number. Note that this ID number is factory-programmed (at the time of manufacture) and it cannot be change once programmed.

The ID number is always 64-bits long, or put another way, comprises 8-bytes (64 bits / 8 bits per byte = 8 bytes). Consider the example ID number (in hex) 01 00 00 1B C8 C6 D1 DE, then you can see that by writing the 8-bytes as hex values it will always be 16 hex digits long. We will see the relevance of this shortly.

These 8-bytes can be broken down into three sections, as follows. The first byte is the family code byte, and in the above example it is '01'. If you refer to the previous section, you will see that the family code value of 01 (hex) represents a DS1990 (ID-only) iButton. The next 6-bytes in the ID number is what some people consider to be the actual ID number – each DS1990 (or any other iButton type) has a unique value in these 6-bytes. The last byte is referred to as the 'CRC' byte.

CRC

The cyclic redundancy check, or 'CRC' byte allows error checking to be performed on the ID number that is read by the microcontroller. It is quite complex, but in essence, when passing the first 7-bytes of the ID number through a fixed algorithm (defined by the manufacturer), the one byte which results from the algorithm's calcutions should match the value of the CRC byte. If it does match, then the data read can be regarded as correct – but, if it doesn't match, then the data read (ie, the attempted read of the ID number) should be discarded. We will discuss this algorithm in a little more detail next month, but for now, the CRC byte should simply be considered as a way to check if the serial data that has been read is valid, or whether contact bounce (between the iButton and the reader/probe) has corrupted it.

Power

A point worth stressing here is that an iButton only has two contacts to the outside world: the 1-Wire serial data-line (sometimes referred to as the 1-Wire bus), and a common ground reference. So how exactly is an iButton powered if it does not have a power connection? The answer is known as 'parasitic power'. Put simply, the 1-Wire data line is pulsed high and low by the connected microcontroller when communication is first initiated, and it is from this pulsing that the iButton can 'steal' some energy to charge a capacitor. This is done through a simple diode-resistor-capacitor circuit inside the iButton. It provides just enough power for the iButton to respond with its data.

Note that SRAM iButtons also contain a battery, but the battery is there just to preserve the SRAM contents; it is not used for powering the iButton itself.

Sizes

iButtons come in two sizes, or to be precise, two different thicknesses, referred to as F3 and F5, where the number indicates the thickness in millimetres – ie, 3mm and 5mm (roughly equal to two or three stacked five-pence coins, respectively). For the precise dimensions, refer to Fig.3 (taken from the manufacturer's datasheet). Note that there is no technical difference between an F3 and an F5 other than its thickness.

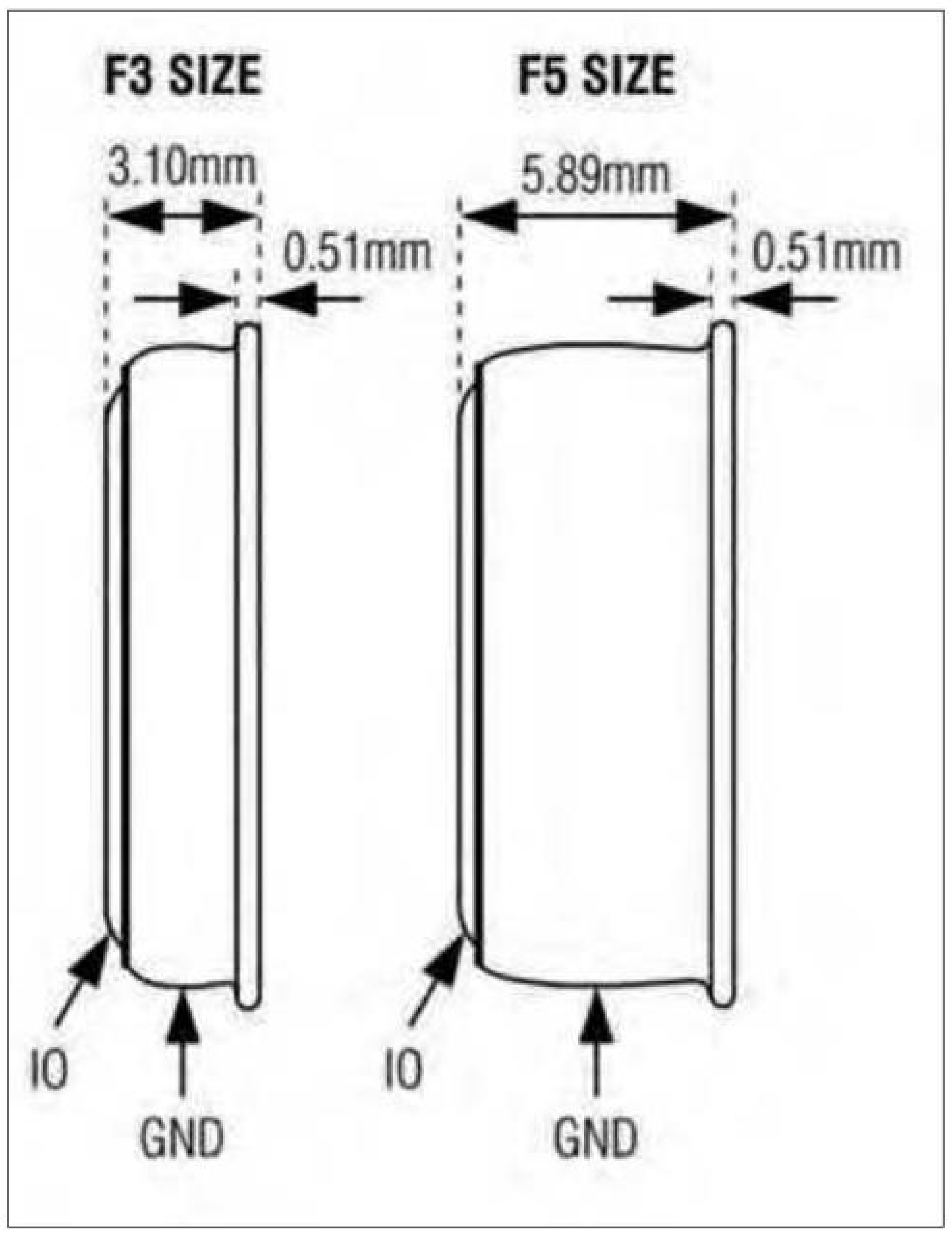

Fig.3. The thickness dimensions of an iButton, showing the two different versions: F3 and F5.

A closer look at the casing

An iButton's metal enclosure comprises two parts, the base and the lid. The base includes the slightly larger diameter bottom of the iButton and also the side of the casing, while the lid is just the top face onto which various markings are stamped by the manufacturer to identify (among other things) the part number. These two metallic parts of the case are connected to the internal IC, and thereby provide the two contacts needed for a microcontroller (via a reader or probe) to communicate with the iButton. Referring to Fig.4, you can see that the larger base section is the ground contact, while the top face is the 1-Wire bus contact.

iButton markings

To understand what the various manufacturer markings represent, please refer to Fig.5. The important thing to point out is that the eight-bytes representing the unique ID number are stamped onto the iButton's case (as hex values) and are laid out in a way that clearly shows the family code byte, the CRC byte, and the remaining 6-bytes of the ID. Using hex values allows this layout to be consistent in length (ie, 16 characters) whereas using decimal values would mean it could be anything between 8 and 24 characters in length – messy!

Across the bottom you see the manufactured year and week number (important when using an iButton that contains a battery), and also the DS part number along with the F3/F5 size. A close-up image of an actual iButton is shown in Fig.6, from which we can confirm it is an F5-sized DS1990 that was manufactured in the 23rd week of 2019. The family code hex-value is '01', and the CRC hex-value is 'DE'. The other six ID byte values are: '00 00 1B C8 C6 D1'.

A very important point to note here is that the family code value '01' shown in the photo is indeed the correct value for a DS1990. I am highlighting this because 'cheap fakes' can often be easily identified when there is a mismatch between the claimed part number and the correct family code value.

1-wire bus

We will not go into the details of the 1-Wire bus here as it can get rather complex. However, in summary, it is a single serial communication line that operates on a 'master/slave' concept. What this means is that the connected microcontroller is the single master, and will initiate communication (which in turn provides the parasitic power to charge the iButton's internal capacitor, as discussed above). By toggling the 1-Wire bus between high and low logic states, the microcontroller can effectively send a command to the iButton. The iButton is the slave, and it decodes the command and responds by sending the required data.

The 1-Wire bus allows for many slaves (iButtons) to be connected to the master (microcontroller). Therefore, the master will first detect any iButtons that are present on the 1-Wire bus, and then follow up typically by sending a command that includes the ID number of the iButton that it wishes to talk to. Hence, all iButtons connected on the 1-Wire bus will receive the message sent by the master, but only the one with a matching ID number will respond (all other iButtons will ignore the message). However, in our application, because we will be using a reader to connect the iButton with the microcontroller, only one slave can physically be present on the 1-Wire bus at any moment in time – this makes communications (and hence our program code) much simpler.

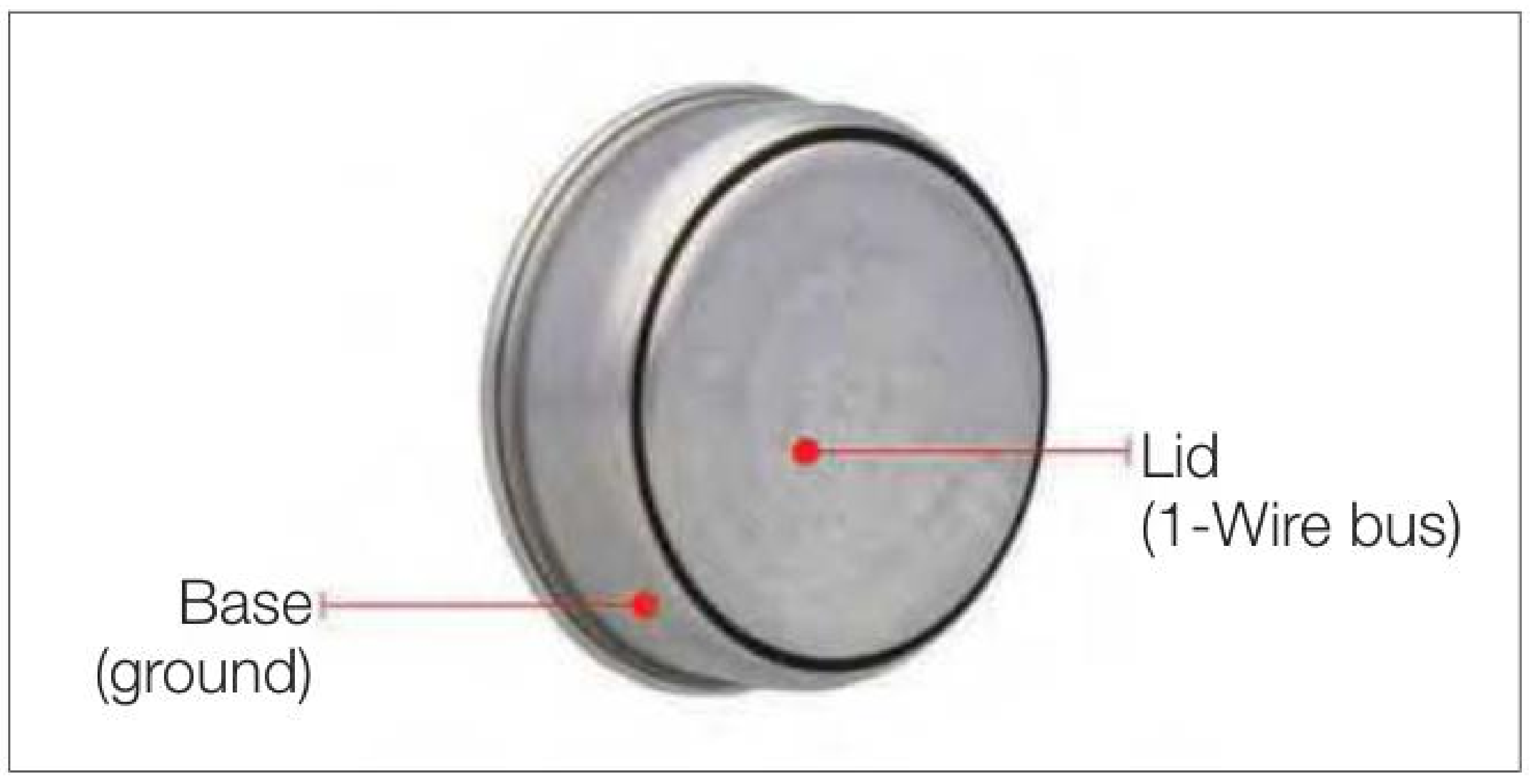

Fig.4. The iButton casing comprises two contacts. The larger of the two is the base (ground), and the top 'lid' is the 1-Wire bus.

There are other commands that the master can send, but I want to keep the explanation simple. However, the most important concept to understand is that the timing of the signal pulses on the 1-Wire bus is critical in order for the system to operate correctly. Thankfully, the MMBASIC firmware handles all this for us. One example of how timing is important is that all communications starts with pulses from the master that will initialise things so that communication with an iButton can commence from a known starting point. Essentially, this initialisation consists of a reset condition transmitted by the master, followed potentially by presence pulse(s) transmitted by any slave(s) that are connected to the 1-Wire bus. The presence pulse then informs the master that an iButton (one or more) is on the 1-Wire bus.

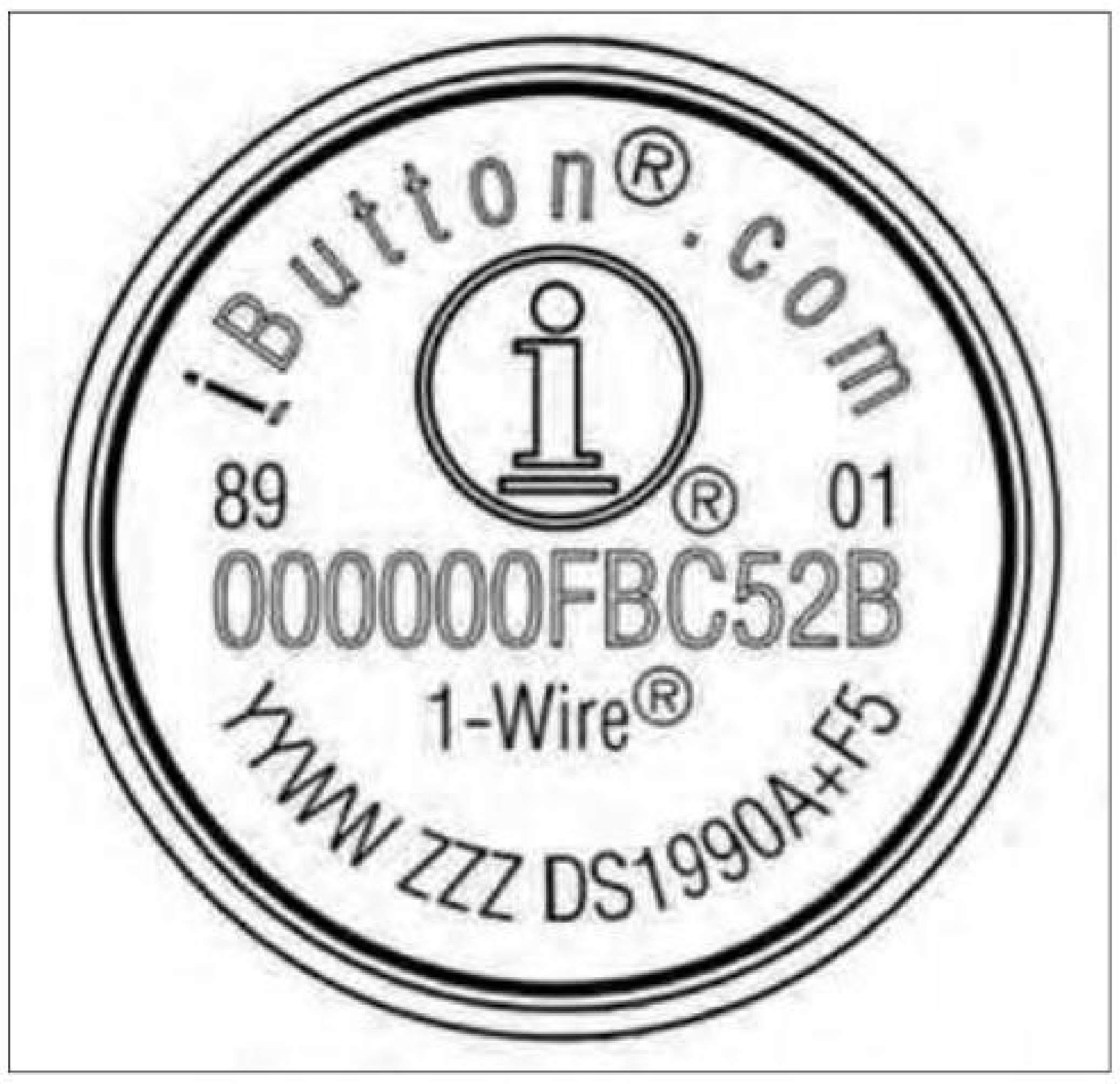

Fig.5. This diagram taken from the datasheet shows the layout of the markings for a genuine iButton from Maxim. The critical things to understand are the location of the family code byte (01) and the CRC (89).

1-Wire commands

As mentioned above, the microcontroller will send a command onto the 1-Wire bus, and any iButton(s) present will receive this command and respond accordingly. The possible commands that the microcontroller can send are referred to as '1-Wire commands' and are represented by a single byte value. When there is just one iButton on the 1-Wire bus (as will be the situation in our case), the most useful command is

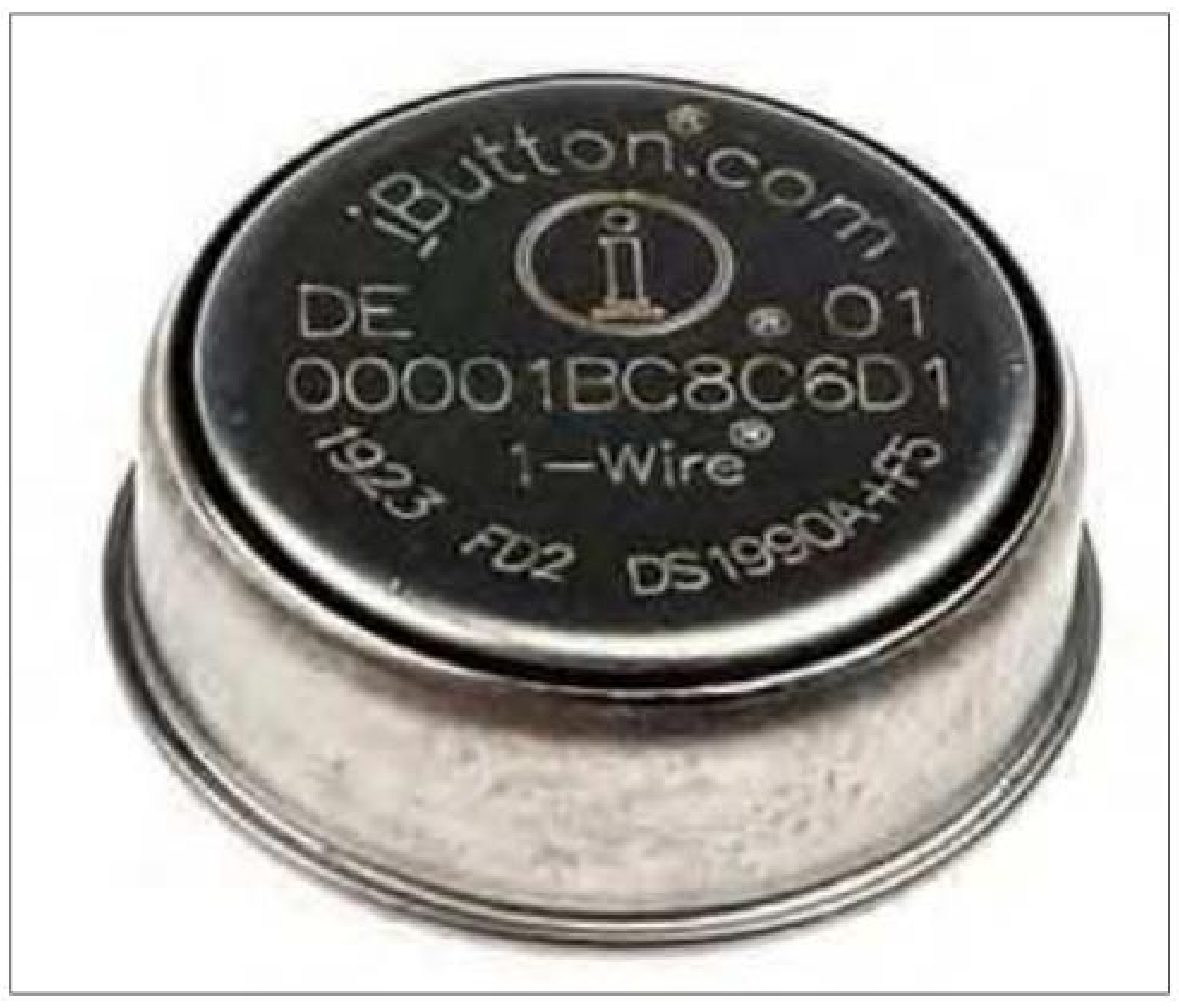

Fig.6. Here the markings of a DS1990 F5 iButton can be seen highlighting the family code (01), CRC (DE) and the remaining 6-bytes of the ID number across the middle of the lid.

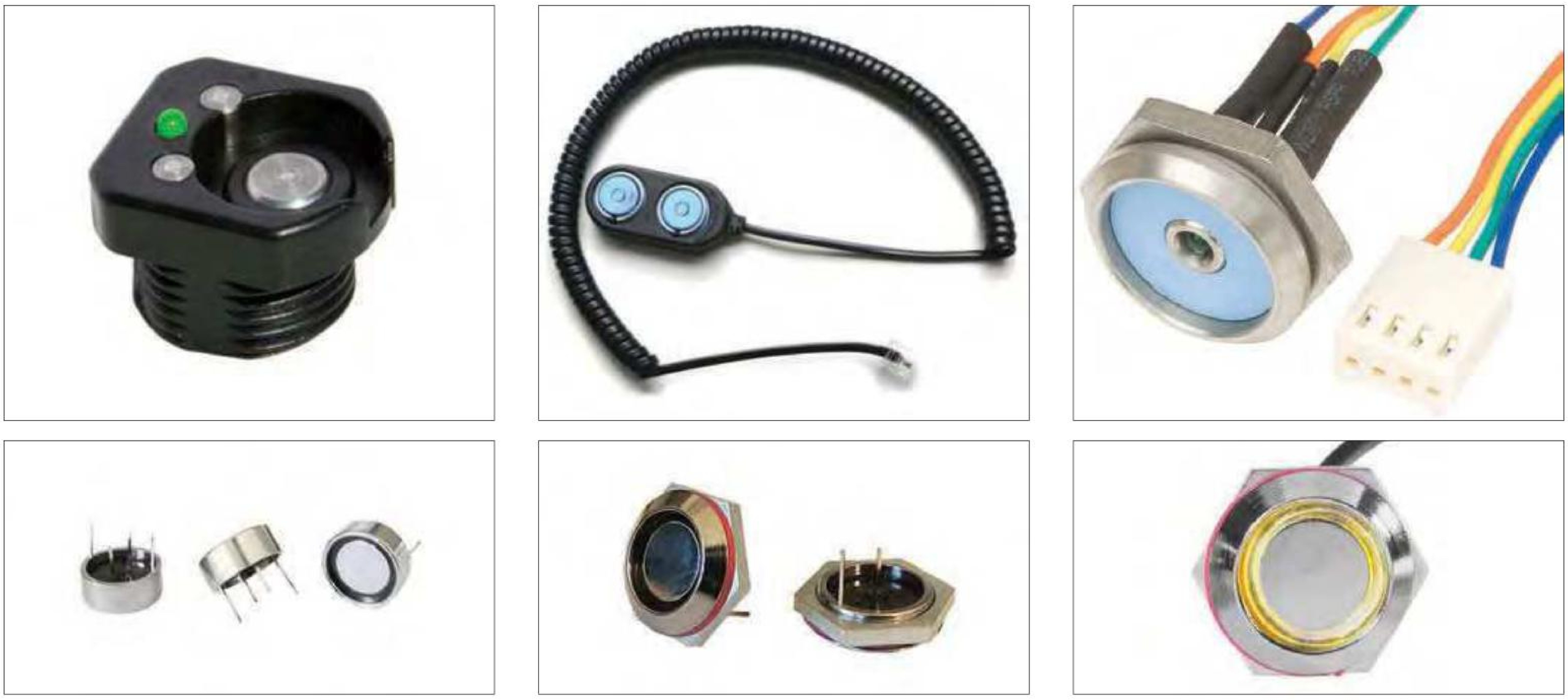

Fig.7. Various iButton readers are available. Some are weatherproof, and some include one or more LEDs. Despite the visual variety, they are all essentially just two metal contacts that make connection to the iButton's base and lid.

`Read Rom`. This command is represented by sending the hex value `33` and will result in the iButton sending its 8-byte ID value. The microcontroller, on receiving this data, can check the family code byte value to ensure the expected type of iButton is present, and use the CRC byte value to ensure the data is correct. If it is, then the ID number is known, and by association can identify the user tapping the iButton, or the asset the iButton is attached to.

Other 1-Wire commands are available and may be specific to only certain types of iButton, but for the DS1990 (ID only) iButton, the `Read Rom` command is the one that we will be using for now. Next month, we will introduce more commands as required when using the DS1971 (ID+EEPROM) iButton – commands that allow us to write to and read from the iButton's EEPROM.

Readers

An online search will lead you to many different versions of iButton readers – see Fig.7 for some examples. There are three main things that should be considered:

1) Does it need to be waterproof?
2) Does the reader need to retain the iButton (rather than just being tapped with the iButton)?
3) Does it need a built-in status LED?

Weatherproof readers are clearly required if being used outdoors and such readers exist for really harsh conditions as may be found on boats. In some situations, it may be a requirement for the iButton to be in contact with the microcontroller for an extended period of time (for example, when reading or writing a large amount of data to memory). In this situation, it is better that the reader 'retains' the iButton, which then avoids contact bounce (and hence corrupted data).

LEDs are typically either single colour, bi-colour, or RGB; and can be mounted as a single led into the reader's housing, or set behind a diffused ring to help locate the place where the iButton needs to be touched (useful for dark environments).

Cost and availability

So how much do these iButtons cost? They start at around £2 each for an ID-only type (ie, the DS1990) and an EEPROM version (ie, the DS1971) starts at around £4. These are the iButtons that we will be using in these articles and the *Electronic Door Lock* mini-project. That said, data-logger iButtons begin at around £10, with the specialist high-capacity data loggers costing anything up to around £150 (yes, you read that correctly!).

Reader prices start at around £4 for simple contact-only type, and cost from around double that for ones with a built-in LED. Please note that a reader is not essential for 'testing' as you could simply use a pair of wires and momentarily touch them onto the iButton; however, a reader makes everything so much easier to use, plus we will need one for our mini-project – which type of reader you use is not relevant because we will also be including a touchscreen that can provide user-feedback. I like to use the DS9092L reader, which incorporates an LED at the centre point and costs around £10. See Fig.7, top right – it shows this specific reader, along with some others that are available.

A Google search will reveal that there are many suppliers of iButton components, including the big global suppliers RS, Farnell, Mouser and DigiKey. However, there is also a very good and reliable small supplier based in the UK that focuses just on iButton parts. This is a company with which I have no affiliation, but they have supplied me many parts in a timely manner and at a sensible cost – this company is HomeChip – see: **www.homechip.com**

MMBASIC 1-Wire Commands

Before we start programming the Micromite to communicate with an iButton, I recommend you have access to *Appendix C* in the *Micromite User Manual*. This is just a single page, but it does give a useful overview of the three 1-Wire commands that are built into MMBASIC (`ONEWIRE.RESET`, `ONEWIRE.WRITE`, and `ONEWIRE.READ`), along with a system variable that we will be using (`MM.ONEWIRE`). It is not essential to read *Appendix C*, just simply have it available for reference should you like to read more about MMBASIC's built in 1-Wire commands.

Demo 1: Detecting an iButton

Let's begin with a program that will simply detect when an iButton is tapped onto the reader. First, we will need to connect the reader (or two wires) to the Micromite plus a 4.7kΩ pull-up resistor, as shown in Fig.8. Any available I/O pin can be used (refer to the *User Manual* if required). Once this is complete, proceed to type in the following code:

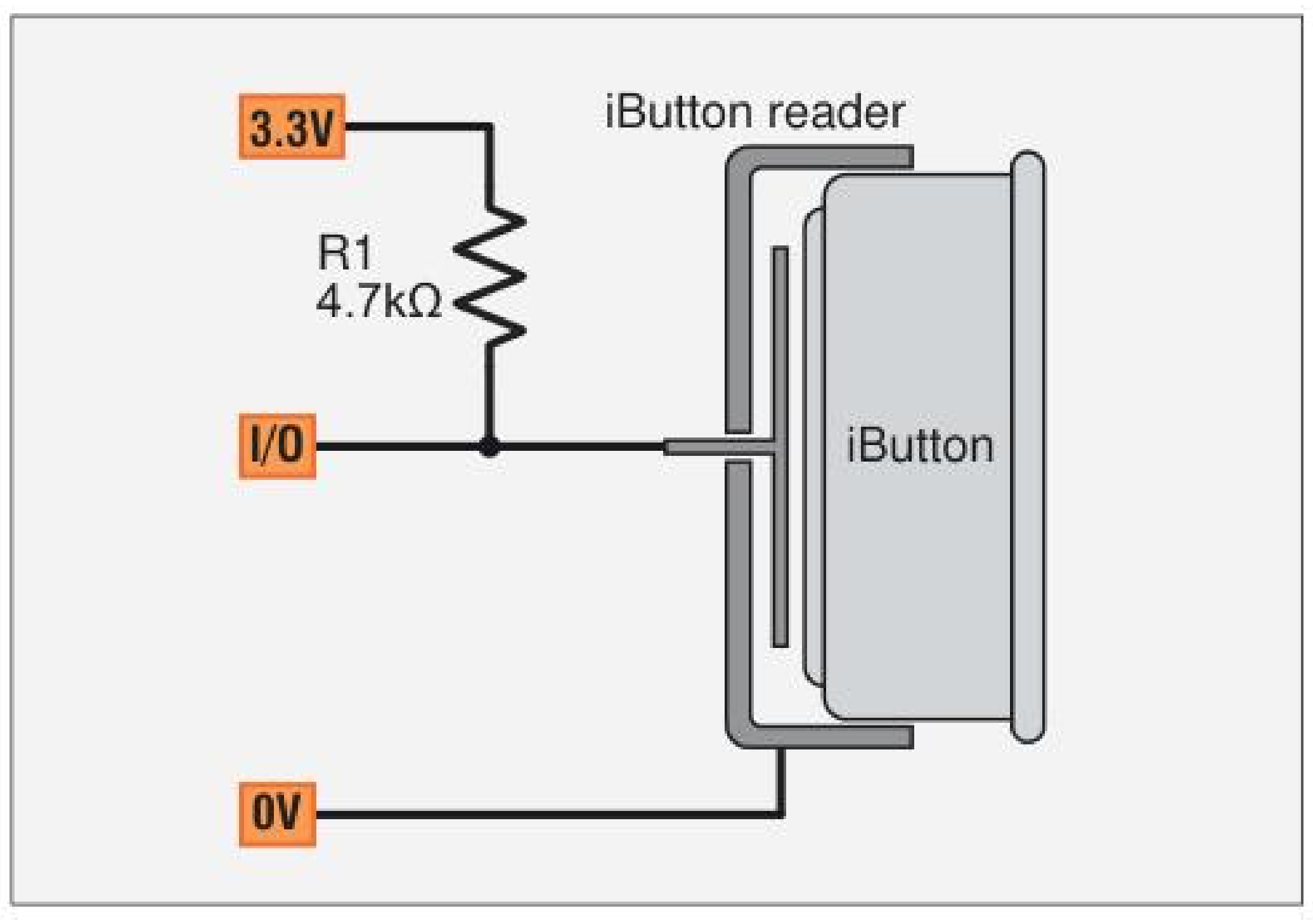

Fig.8. The circuit consists of connecting the 1-Wire Bus to any available I/O pin (ensure there is a 4.7kΩ pull-up resistor), and also connecting a common ground.

```
iB_pin= 9
DO
  ONEWIRE RESET iB_pin
  PRINT MM.ONEWIRE
  PAUSE 10
LOOP
```

Before you `RUN` the program, we will explain what each of the six lines does. The first simply defines the I/O pin to which the 1-Wire bus (ie, the iButton 'lid') is connected to. This pin number is loaded into the variable that we have called `iB_pin` (don't forget to change the value from `9`, to the I/O pin number that you're using if it is different).

The second line (and last) create an endless `DO`/`LOOP` that contain two 1-Wire references (on lines 3 and 4), and a pause for 10ms (line 5) that slows things down a little. Each time the code in the loop is executed, the `ONEWIRE RESET iB_pin` (line 3) causes the Micromite to send a RESET pulse to pin 9 (or whatever pin number is loaded into the variable `iB_pin`). The specific timings are fully handled by MMBASIC and make things so much easier for us. The end result will be that the `MM.ONEWIRE` system variable is then loaded with either a 0 (if no iButton responded), or a `1` if an iButton was detected. Line 4 simply prints this value to the Terminal screen (ie, to the TeraTerm screen). This loop is repeated over and over every 10ms.

Now `SAVE` the program and then `RUN` it. You should see a column of 0s appear down the left side of your Terminal screen. If you now tap and hold an iButton (any type) onto the reader, the column of `0`s should change to `1`s. Note that you will likely see contact bounce in the form of the occasional `0` or `1` appearing when not expected – this is normal, and is the reason we need to use the CRC byte value to check the validity of any data we read.

If everything works as described then move onto Demo 2. However, if something is not working as expected, then you will need to resolve the issue by working through the next *Troubleshooting* section.

Troubleshooting Demo 1

If an error is generated when you `RUN` the program then the error reported should highlight what the issue is. The most common mistake (other than typos) is to use an invalid pin number (the error message will show if this is the case). Any syntax error is most likely a typo. If, after checking your code, the program is still not responding to an iButton being tapped on the reader, the likelihood is that either the wrong pin is being connected to (for example the code refers to pin 9, but physically the iButton is being connected to pin 10), or the pull-up resistor is either missing or the wrong value. Don't forget the common ground connection too.

If after checking the software and the hardware it is still not functioning correctly, then send me an email and I will try and assist you.

Demo 2: Displaying the ID number

This demo can be download from the January 2022 page of the *PE* website. Again, simply `RUN` it to see the outcome. We will explain its operation next month, but in the meantime, why not take a quick look at the code and see if you can begin to grasp what is happening. If you struggle, don't panic, we will cover this at the start of the next article.

Next month

We will begin next month by explaining Demo 2 in more detail, and then look in greater depth at the CRC algorithm. We will then discuss the DS1971 (256-bit EEPROM) iButton and show how to write to and read data from it. Until then, *Have Fun!*

Questions? Please email Phil at:
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HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHz – 20GHz	£2,000
HP83630A	Synthesised Sweeper 10MHz – 26.5 GHz	POA
HP83624A	Synthesised Sweeper 2 – 20GHz	POA
HP8484A	Power Sensor 0.01-18GHz 3nW-10µW	£75
HP8560E	Spectrum Analyser Synthesised 30Hz – 2.9GHz	£1,750
HP8563A	Spectrum Analyser Synthesised 9kHz – 22GHz	£2,250
HP8566B	Spectrum Analsyer 100Hz – 22GHz	£1,200
HP8662A	RF Generator 10kHz – 1280MHz	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325
Marconi 2024	Synthesised Signal Generator 9kHz – 2.4GHz	£800
Marconi 2030	Synthesised Signal Generator 10kHz – 1.35GHz	£750
Marconi 2023A	Signal Generator 9kHz – 1.2GHz	£700

Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHz	£295
Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 2955B	Radio Communications Test Set	£800
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHz – 20GHz	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B	Power Meter with 6910 sensor	£295
Tektronix TDS3052B	Oscilloscope 500MHz 2.5GS/s	£1,250
Tektronix TDS3032	Oscilloscope 300MHz 2.5GS/s	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHz 1.25GS/s	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHz 100MS/s	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHz	£600
Farnell AP60/50	PSU 0-60V 0-50A 1kW Switch Mode	£300
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell AP100-90	Power Supply 100V 90A	£900
Farnell LF1	Sine/Sq Oscillator 10Hz – 1MHz	£45
Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
Racal 9300B	As 9300	£75
Solartron 7150/PLUS	6½ Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHz – 20kHz	£600
Solartron SI 1255	HF Frequency Response Analyser	POA
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160 – £200
Thurlby TG210	Function Generator 0.002-2MHz TTL etc Kenwood Badged	£65

HP/Agilent HP 34401A Digital
Multimeter 6½ Digit £325 – £375

HP33120A	Function Generator 100 microHz – 15MHz	£350
HP53131A	Universal Counter 3GHz Boxed unused	£600
HP53131A	Universal Counter 225MHz	£350
Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

Marconi 2955B Radio
Communications Test Set – £800

AOShop

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors

AC125, NKT214F, OC57 OC59	£1.00

Low-noise PNP transistors

GET106	£2.50

Small power PNP transistors

AC153, AC153K, AC188	£1.50

High-voltage PNP transistors

OC77, CV7001, ACY20	£1.50

TO3 PNP power transistors

OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	£2.00
AD140	£3.50
AD149 matched pair	£5.00

RF PNP transistors

OC41, OC42, 2SA12, 2SA53,AF124, AF128, GET872A	£1.50

NPN transistors

OC139, OC140, ASY73, AC141K, AC176K, AC176	£2.00

Diodes

CV7049 (OA10), CG92 (OA91)	£0.50

Si semiconductors

Diodes

ZC5800 RF Schottky	£0.20

Low-noise silicon transistors

BFW16A, 2SC3071	£1.50
2SC2204, 2SD655	£0.50
ZTX651	£0.30

RF transistors (suitable for Theremin)

BF199	£0.50
BF245	£0.60

Audio power MOSFETs

Exicon 10N20, 10P20	£6.50
Hitachi 2SJ99, 2SK343	£3.50
Hitachi 2SJ 50, 2SK135	£7.00
Hitachi 2SJ56, 2SK176	£8.50

JFETs

BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176	£1.00

MOSFETs

ZVP2106A	£0.30
Dual-gate 3SK45, BFS28	£1.50

Metal-cased transistors

BC143	£0.35
2N1711	£0.50
BCY71	£0.30
BC109C	£0.60

Amplifiers

TL082 dual JFET input op amp	£0.25
LM318 high-speed op amp	£0.35
µA709 metal-cased op amp	£2.00
5534H metal-cased op amp	£3.00
LM384, TDA2030A	£1.50
TAA435 (power amp driver)	£1.20

Synthesiser ICs

That/dbx 2180 VCA/VCF	£6.00
CA3080 VCA/VCF (vocoder)	£2.80
CA3082 VCA/VCF	£4.00
LM13600/ LM13700 VCA/VCF	£2.00
CA3086 transistor array	£1.00
PT2399 echo/delay	£1.50

Dual transistors

2N2639, 2N2223, 2N2910 (NPN)	£4.00
E401 (JFET)	£4.00
DMMT3904/6	£0.50

Loudspeakers

PE Mini-Monitor

Volt PE165 6.5-inch woofer (each)	£85
Morel MDT29 tweeter (each)	£25
Kit *pair* of PE165/MDT29 plus Volt crossover parts and PCBs	£299
Monacor DT-28N tweeter (each)	£45
Vifa 19mm BC20SC15-04 tweeter (each)	£15
Volt PE110 5-inch woofer (each)	£75

Volt crossover inductors

1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	£5.85
LS3/5A transformer-core 15Ω assembled crossover board (each)	£60

Fully assembled and tested high-quality speaker prototypes – ask for details

LS3/5As and other similar speaker systems (pair)	£200-£350

Fully tested reclaimed speakers

Vifa BC14 5-inch woofer (each)	£15
Vifa TC26 1-inch tweeter (each)	£15

Low-price speakers

Celestion elliptical 6x4-inch 5Ω (Robert's Radio)	£3.50
Philips 4-inch 4070	£2.00
EMI 10x6-inch, 30Ω Alnico	£10
64mm 64Ω neodymium	£1.20
3.5-inch 25Ω	£3.50
5x3-inch elliptical 50Ω or 80Ω Alnico	£3.50
1.65x2.75-inch 8Ω	£1.50

Can't see what you want? Just ask – we have a huge stock of inexpensive high-quality parts!

Capacitors

Note '10/63' denotes '10µF 63V'.

Polyester

3.3/100, 4.7/250, 4.7/63	£1.00
5.6/63, 8.2/63, 10/63	£2.00
Mullard 'Mustard' C296 0.22/400	£2.00

Polycarbonate

Axial 2.2/63 1%, 4.7/160, 6.8/63	£1.00

Radial

6.8/160V, 10/63	£2.00
Reclaimed 22/63	£2.00

Polystyrene

Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63	£1.00
RIFA 1% 100nF/100	£2.00
Suflex 2.5% 10nF/63 (rad. or ax.)	£0.50

Radiation resistant

Siemens cellulose acetate MKL 2.2/25	£0.80

Electrolytic – Mullard blue 017 series

10/25, 22/25, 100/10	£0.50
150/40, 470/40,1000/40	£1.00

Tantalum – metal cased

22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	£2.00
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	£1.25
4.7/50, 6.8/35, 10/25, 10/35, 22/15	£1.00

Moulded-case tantalum

Kemet axial 6.8/10	£0.30
Kemet radial 33/10	£0.40
STC radial 100/20	£1.50

Tantalum bead

22/50	£1.00
470/3	£2.00
680/6.3	£3.00

Wet tantalum

220/25 axial	£3.20
Castanet button 140/30, 470/3	£3.20
Hughes 540/10	£3.20

Bipolar

Hermetic bipolar tantalum 16/35	£3.20
Callins Elcap wet aluminium 10/50	£0.50

Philips solid-aluminium (axial) 121/123

47/16	£1.00
330/6.3	£2.00
100/35	£4.00

Philips Pearl 122 series (radial)

10/16	£0.30
10/25	£0.50

Silvered mica (radial)

4.7nF/500 5%	£1.00

Trimmer capacitors

Vishay plastic-film 4-40pF	£0.80
Vishay plastic-film 5.5-45pF	£1.00
Vishay plastic-film 5-80pF	£1.20
Vishay plastic-film 10-250pF	£2.00
Mica 1-12pF, 2-40pF	£1.00

Audio transformers and inductors

Eagle transformers

LT44, LT722 driver, LT700, LT723 500Ω output	£2.50
LT30 500mW output	£3.50

Repanco

T/T3 splitter transformer	£4.00
CH2 5mH RFC	£2.00

Balanced output transformer

Vigortronix 600Ω VTX-101-007	£10
Vigortronix 600Ω VTX-101-3001	£10
Vigortronix 600Ω VTX-101-3002	£15
Gardners 150Ω	£10
Reclaimed BBC LL74/MPC nickel core 600Ω	£12
Reclaimed mic input transformer	£15

Inductors

82µH, 4.7mH, 100µH, 270µH	£2.00
7-inch ferrite rod with MW and LW windings	£3.00

Special resistors

Bourns wire-wound trimmer 5kΩ 3059 JM panel-mount	£2.00
Thermistor RA53, A13	£4.00
Thermistor CZ1, CZ6	£1.50
Holco H2 2.2MΩ 1W, 1%	£1.00
Welwyn 1GΩ 2W	£1.00
Allen Bradley 1.2kΩ 2W C-comp	£1.00

Lots of big valve resistors available.

Potentiometers

Bourns 81

25kΩ lin cermet	£2.00
25kΩ lin conductive plastic	£3.00

Plessey moulded-track

5kΩ log with switch	£3.00
50kΩ A/log	£3.00
Mil 250kΩ lin dual	£5.00

Alpha

16mm 4.7kΩ A/log	£0.80
220kΩ A/log	£0.80
10kΩ lin centre-detent dual-gang	£1.50

Allen Bradley J series/Honeywell 10kΩ lin 1 million cycles	£5.00
Blore Edwards AB 45 dual 5kΩ A/log with switch	£3.50
Alps RK9 dual-gang 5kΩ RD law	£4.00
BI P260 500kΩ log conductive plastic 1 million cycles	£3.00
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	£8.00
Mil Spec hermetic 10Ω	£8.00

Miscellaneous

Theremin Clearance Sale!

Elysian Theremin MIDI box	£300

PCBs

Pocket Theremin (*EPE*, 1996)	£4.00
Elysian Theremin (*EPE*, 1996)	£12
Synth VCF, VCO (*EPE*, 2017)	£3.00
48V PSU (*EPE*, 2019)	£3.00

Relays

STC hermetic 4190 24V DPDT	£4.00

Switches Blore Edwards/Plessey

MH1 4-pole 3-way	£3.00
Elma 01 2-pole 6-way	£6.00
3PDT guitar pedal stomp switch	£2.50

Valves

EC88, PCL84	£3.00

Robert's Radio modules

Tuners LP1169, LP1179	£7.00
IF strip LP1171	£7.00

Knobs – large Bakelite

Bulgin 1960s and Sifam 1970s	£1.50

Contact
Jake Rothman
The Old Rectory, Arlais Road,
Llandrindod Wells, Powys
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+44 (0)1597 829102
jrothman1962@gmail.com

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Practical Electronics PCB SERVICE

PROJECT	CODE	PRICE
JANUARY 2022		
Vintage battery Radio Li-ion Power Supply	11111201	9.95
MiniHeart: A Miniature Heartbeat Simulator	01109201	8.95
DECEMBER 2021		
AM/FM/SW Digital Receiver	CSE200902A	13.95
Balanced Input and Attenuator for USB CODEC	01106202	11.95
NOVEMBER 2021		
Dual Battery Lifesaver	11111202	£6.95
OCTOBER 2021		
Mini Wi-Fi LCD BackPack	24106201	£8.95
SEPTEMBER 2021		
USB SuperCodec PCB	01106201	£14.95
Audio DDS Oscillator PCB	01110201	£5.95
Audio DDS Oscillator rotary encoder	01110201-ENC	6.95
Programming Adaptor Board for Audio DDS Oscillator	01110202	£5.95
High-power Ultrasonic Cleaner main PCB	04105201	£14.95
High-power Ultrasonic Cleaner front-panel PCB	04105202	
Night Keeper Lighthouse PCB	08110201	£5.95
AUGUST 2021		
Ol' Timer PCB	19104201	£11.95
Ol' Timer 8x8 RGB LED module using WS2812B	19104201-88	£8.95
Ol' Timer set of acrylic case pieces and spacer	19104201-ACR	£8.75
Ol' Timer DS3231 RTC IC wide SOIC-16	19104201-RTC	£5.95
Wideband Digital RF Power Meter	04106201	£9.75
Switchmode 78xx regulators ***(PACK of 5!)***	18105201	£7.95
Cool Beans SMAD display	CB-AUG21	£11.95
JULY 2021		
ATtiny816 Breakout / Dev Board with Capacitive Touch	24110181	£9.75
IR Remote Control Assistant (Jaycar version)	15005201	£8.95
IR Remote Control Assistant (Altronics version)	15005202	£8.95
PIC18F Development Board	PNM-JUL21	£12.95
Microphone Preamplifier	AO-JUL21	£11.95
JUNE 2021		
Roadies' Test Signal Generator (surface-mount version)	01005201	£8.95
Roadies' Test Signal Generator (through-hole version)	01005202	£9.95
Touchscreen Wide-range RCL Box (Resistor module)	04104201	£18.95
Touchscreen Wide-range RCL Box (Ind/Cap module)	04104202	
KickStart Part 3 – Gyrator-based Audio Filter	KS3-2021	£7.95
MAY 2021		
7-Band Equaliser (Mono)	01104201	£8.95
7-Band Equaliser (Stereo)	01104202	£10.95
Car Altimeter	05105201	£7.95
APRIL 2021		
Reflow Oven – DSP Active Crossover (CPU)	01106193	£19.95
Reflow Oven – DSP Active Crossover (Front panel)	01106195	
Reflow Oven – DSP Active Crossover (LCD)	01106196	
Frequency Reference Signal Distributor	CSE200103	£8.95
MARCH 2021		
Nutube Guitar Effects Pedal	01102201	£12.95
Programmable Thermal Regulator (Peltier Interface)	21109181	£18.95
Programmable Thermal Regulator (Peltier Driver)	21109182	
Tunable HF Preamp	CSE190502	£8.95
FEBRUARY 2021		
4G Remote Monitoring	27111191	£9.95

PROJECT	CODE	PRICE
JANUARY 2021		
Nutube Valve Preamplifier	01112191	£12.95
Arduino DCC Controller	09207181	£10.95
DECEMBER 2020		
Pseudo-Random Sequence Generator	16106191	£7.95
Clever Charger	14107191	£11.95
PE Theremin Amplifier	AO-1220-01	£8.95
NOVEMBER 2020		
LED Christmas Tree (1 off)	16107181-1	£6.95
LED Christmas Tree (4 off)	16107181-2	£14.95
LED Christmas Tree (12 off)	16107181-3	£24.95
LED Christmas Tree (20 off)	16107181-4	£34.95
USB/SPI Interface Board	16107182	£5.95
45V/8A Power Supply PCB *plus* acrylic spacer	18111181	£14.95
45V/8A Power Supply front panel five-way display bezel	18111181-BZ	£3.95
Five-way LCD Panel Meter/Display	18111182	£7.95
OCTOBER 2020		
Digital Audio Millivoltmeter	04108191	£9.95
Precision Signal Amplifier	04107191	£7.95
SEPTEMBER 2020		
PE Theremin PSU	AO-0920-01	£5.95
PE Theremin PSU transformer	AO-0920-02	£7.95
Micromite Explore-28	07108191	£6.95
Ultrabrite LED Driver	16109191	£6.95
AUGUST 2020		
Micromite LCD BackPack V3	07106191	£9.95
Steering Wheel Audio Button to Infrared Adaptor	05105191	£7.95
JULY 2020		
AM/FM/CW Scanning HF/VHF RF Signal Generator	04106191	£13.95
Speech Synthesiser with the Raspberry Pi Zero	01106191	£5.95
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PE Mini-organ selected parts	AO-0720-02	£8.95
High-current Solid-state 12V Battery Isolator – control	05106191	£6.95
High-current Solid-state 12V Battery Isolator FET (2oz)	05106192	£9.95
JUNE 2020		
Arduino breakout board – 3.5-inch LCD Display	24111181	£6.95
Six-input Audio Selector main board	01110191	£10.95
Six-input Audio Selector switch panel board	01110192	
MAY 2020		
Ultra-low-distortion Preamplifier Input Selector	01111112	£11.25
Ultra-low-distortion Preamplifier pushbutton Input Selector	01111113	
Universal Regulator	18103111	£7.95
433MHz Wireless Data Repeater	15004191	£8.50
Bridge-mode Adaptor for Amplifier	01105191	£7.95
iCEstick VGA Terminal	02103191	£5.95
Analogue noise with tilt control	AO-0520-01	£7.95
Audio Spectrum Analyser	PM-0520-01	£8.95
APRIL 2020		
Flip-dot Display black coil board	19111181	£14.95
Flip-dot Display black pixels	19111182	
Flip-dot Display black frame	19111183	
Flip-dot Display green driver board	19111184	
MARCH 2020		
Diode Curve Plotter	04112181	£10.95
Steam Train Whistle / Diesel Horn Sound Generator	09106181	£8.50
Universal Passive Crossover (one off)	UPC0320	£12.50

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

PROJECT	CODE	PRICE
FEBRUARY 2020		
Motion-Sensing 12V Power Switch	05102191	£5.95
USB Keyboard / Mouse Adaptor	24311181	£8.50
DSP Active Crossover (ADC)	01106191	£29.95
DSP Active Crossover (DAC) ×2	01106192	
DSP Active Crossover (CPU)	01106193	
DSP Active Crossover (Power/routing)	01106194	
DSP Active Crossover (Front panel)	01106195	
DSP Active Crossover (LCD)	01106196	
JANUARY 2020		
Isolated Serial Link	24107181	£8.50
DECEMBER 2019		
Extremely Sensitive Magnetometer	04101011	£16.75
Four-channel High-current DC Fan and Pump Controller	05108181	£8.75
Useless Box	08111181	£11.50
NOVEMBER 2019		
Tinnitus & Insomnia Killer (Jaycar case – see text)	01110181	£9.95
Tinnitus & Insomnia Killer (Altronics case – see text)	01110182	£9.95
OCTOBER 2019		
Programmable GPS-synced Frequency Reference	04107181	£11.50
Digital Command Control Programmer for Decoders	09107181	£9.95
Opto-isolated Mains Relay (main board)	10107181	£11.50
Opto-isolated Mains Relay (2 × terminal extension board)	10107182	
AUGUST 2019		
Brainwave Monitor	25108181	£12.90
Super Digital Sound Effects Module	01107181	£6.95
Watchdog Alarm	03107181	£8.00
PE Theremin (three boards: pitch, volume, VCA)	PETX0819	£19.50
PE Theremin component pack (see p.56, August 2019)	PETY0819	£15.00
JULY 2019		
Full-wave 10A Universal Motor Speed Controller	10102181	£12.90
Recurring Event Reminder	19107181	£8.00
Temperature Switch Mk2	05105181	£10.45
JUNE 2019		
Arduino-based LC Meter	04106181	£8.00
USB Flexitimer	19106181	£10.45
MAY 2019		
2× 12V Battery Balancer	14106181	£5.95
Deluxe Frequency Switch	05104181	£10.45
USB Port Protector	07105181	£5.95
APRIL 2019		
Heater Controller	10104181	£14.00
MARCH 2019		
10-LED Bargraph Main Board	04101181	£11.25
+Processing Board	04101182	£8.60
FEBRUARY 2019		
1.5kW Induction Motor Speed Controller	10105122	£35.00
NOVEMBER 2018		
Super-7 AM Radio Receiver	06111171	£27.50
OCTOBER 2018		
6GHz+ Touchscreen Frequency Counter	04110171	£12.88
Two 230VAC MainsTimers	10108161	£12.88
	10108162	

PROJECT	CODE	PRICE
SEPTEMBER 2018		
3-Way Active Crossover	01108171	£17.95
Ultra-low-voltage Mini LED Flasher	16110161	£5.95
AUGUST 2018		
Universal Temperature Alarm	03105161	£7.95
Power Supply For Battery-Operated Valve Radios	18108171	£24.95
	18108172	
	18108173	
	18108174	
JULY 2018		
Touchscreen Appliance Energy Meter – Part 1	04116061	£14.95
Automotive Sensor Modifier	05111161	£12.95
JUNE 2018		
High Performance 10-Octave Stereo Graphic Equaliser	01105171	£14.95
MAY 2018		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£8.45
Microbridge	24104171	£5.95

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DIRECT BOOK SERVICE

Teach-In 2017

Introducing the BBC micro:bit

PYTHON CODING ON THE BBC MICRO:BIT

Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

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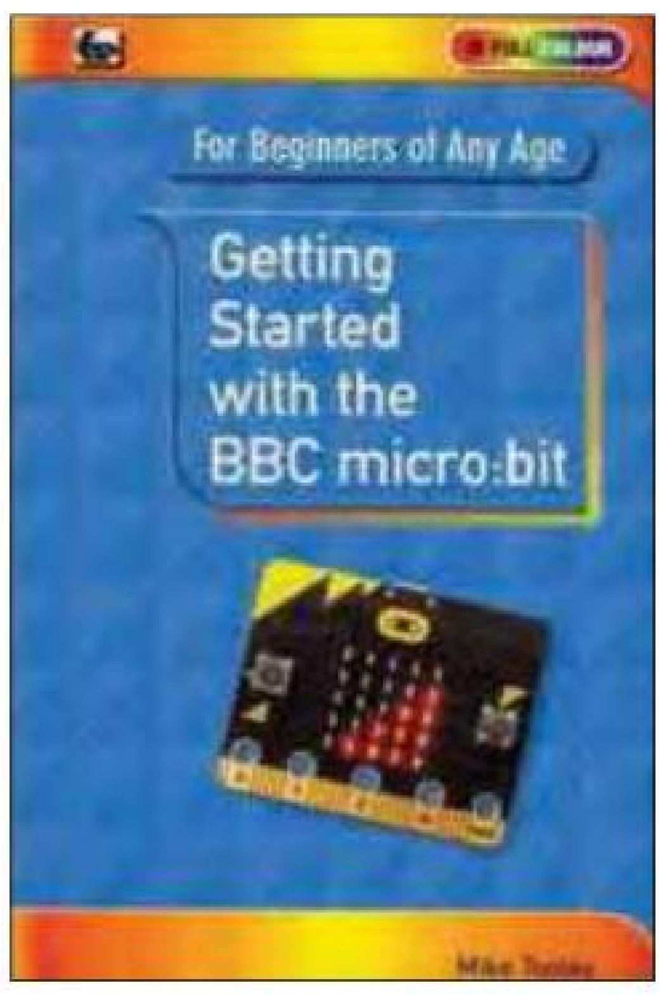

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Mike Tooley

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Next Month – in the February issue

Arduino-based Adjustable Power Supply

We have published all sorts of fancy bench supplies over the years: linear, switchmode, hybrid, high-voltage, high-current, dual-tracking... But sometimes, all you need is a basic power supply with voltage and current monitoring and limiting; something that's convenient and easy to set up and use. That's exactly what this is – a very useful little power supply built on an Arduino shield.

Battery Multi Logger

Knowing the condition of your batteries is essential for keeping them healthy longterm. A system that can monitor and log vital battery statistics is a great aid, and can help you avoid having to shell out for expensive replacements. It can also be used for troubleshooting.

Electronic Wind Chimes

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Mini Digital AC Panel Meters

In this follow-up article on low-cost digital panel meters, we're looking at meters designed to measure AC voltages and currents. Some of them can even calculate and display power, energy consumption and frequency. We'll explain how they work, how they perform and how easy they are to use.

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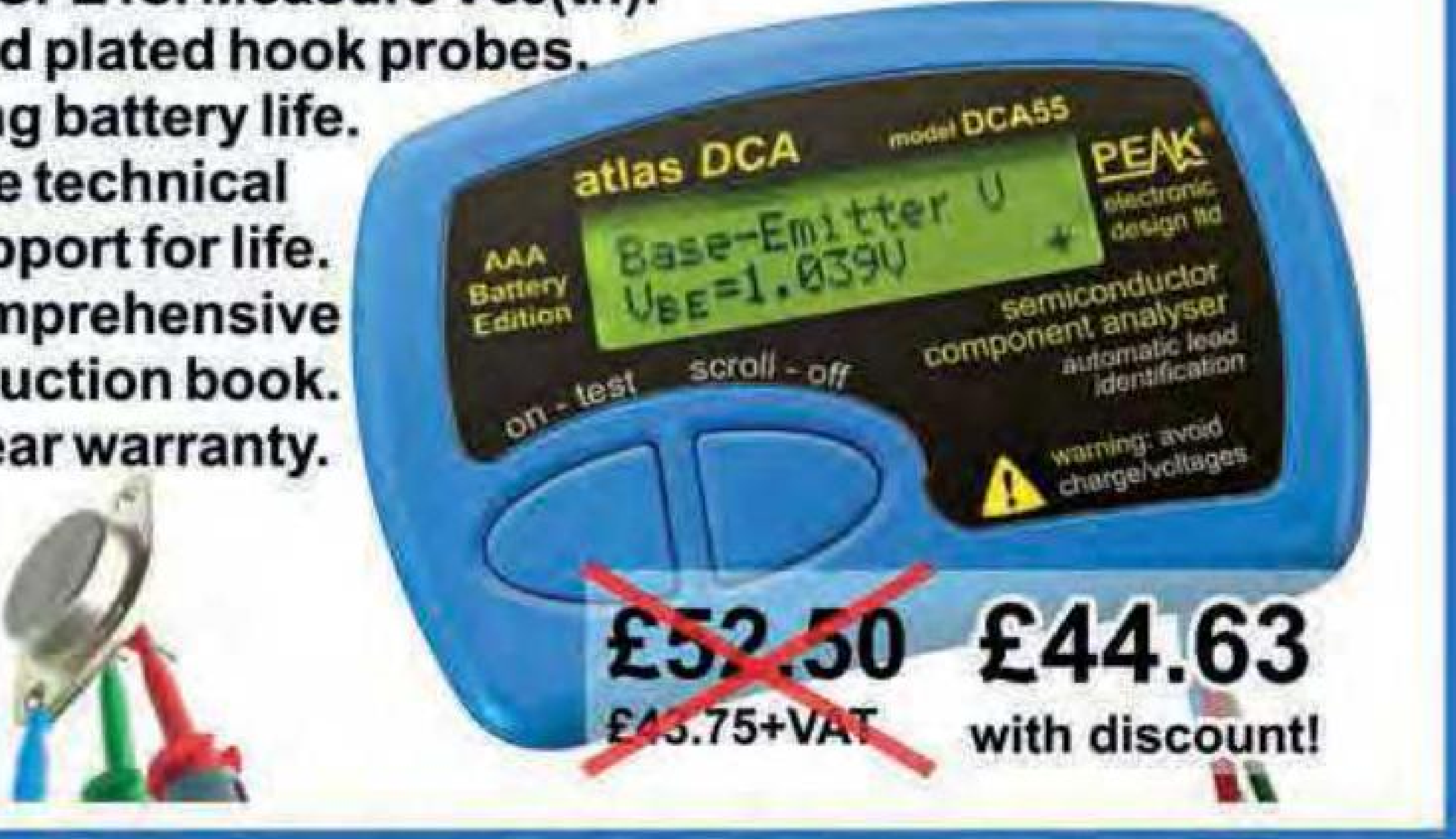
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